INSHORE LAKE MICHIGAN FISH POPULATIONS NEAR THE D. C. COOK NUCLEAR POWER PLANT DURING PREOPERATIONAL YEARS - 1973, 1974

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GENERAL INTRODUCTION

One result of our advanced technology is the production of electricity from nuclear power. Engineering and safety features of such an immense undertaking are planned and tested. However, the biological effects of using large amounts of water for cooling purposes are not studied to the extent that engineering facets are.

The growing human population in the Great Lakes basin and its increasing consumption of electrical energy has created the need for more electrical power. A decision to build a power plant to meet these needs must be based on economics, availability of a suitable site, cost-benefit calculations, present availability of fuel, and biological considerations. The Lake Michigan Federation (1975) listed 45 power-generating stations on Lake Michigan. In addition to those power plants which demand large volumes of water from Lake Michigan for once-through cooling purposes, there are a large number of domestic and industrial intakes which also draw water from the lake. Since the inshore waters are generally the most productive and act as nursery areas for a number of fish, many adult fish are impinged and fish larvae entrained at these intake screens.

At the present time most research on these problems, including ours, has been site-specific. We will present information concerning the composition of fish populations in the vicinity of the D. C. Cook Nuclear Plant, as well as the magnitude of the entrainment and impingement problems experienced. Since some future predictions (Edsall 1976) indicate that by the year 2020, about 98% of the total power requirement will be met by nuclear-fueled steam electric plants, we must learn about the biological problems created by present plants, so we are prepared to answer questions and make more accurate predictions about future plants in the area of plant siting, intake construction and location. At some point, lake-wide assessments of the entrainment and impingement problems at all water intakes on each of the Great Lakes must be made.

Our studies at the Cook Plant have established the temporal and spatial distribution of juvenile, adult and larval fish in the inshore waters of Lake Michigan near the plant. We know with relative certainty the magnitude of the entrainment and impingement losses at the plant. We have explored and now know the limits of the data base, both from a biological and a statistical standpoint. Adult and larval fish populations are extremely mobile; adults, particularly salmonids, are known to range widely over the entire lake and fish larvae can be transported long distances due to wind- and storm-induced currents. These problems make satisfying the assumptions of parametric statistical analyses very difficult.

It is our opinion that we have probed the limits of the state-of-the-art of determining the effect the Cook plant has on fish populations under its influence. The recent symposium on 3-6 May 1977 on assessing the effects of power plant-induced mortality on fish populations (Van Winkle

1977) grappled with the massive and complex problem of determining exactly what level of mortality a given plant caused to a target fish species, and more complicated still, what levels of compensation occurred among the remaining fish in the impacted population. We have a similar dilemma in trying to ascertain what the annual destruction of 200,000 impinged fish, mostly alewives, and a million or more fish larvae entrained per day during the peak spawning period means to the respective populations in Lake Michigan. There are no easy answers to these questions.

Within this report the reader will find five sections each concerned with a specific area of fisheries monitoring. The statistical section (A) discusses the major statistical tests used on the various data sets, the assumptions behind each test and how well they were satisfied, transformations and least detectable true differences.

Section B contains a discussion of the juvenile and adult fish populations, their temporal and spatial distribution by age groups, how they reacted to upwellings, statistical results, spawning times, temperature-catch relationships and usually some statements about their use as forage or in the case of predators, their feeding habits. Statements about differences in numbers and growth of fish between 1973 and 1974 are made. Sex ratios, parasite data and diseases noted are recorded when it is considered appropriate. Another section on impingement (Section E) documents the numbers, weight and species impinged by the plant during 1973 and 1974. Seasonal changes in abundance of the different species impinged are discussed in terms of what species and lengths of juvenile and adult fish were present around the plant as determined from our field monitoring data. Problems of forebay residence by fish prior to impingement, effect of upwellings and storms on impingement rates and species composition and notes on fish distribution during times when we could not sample (winter) are discussed.

Two other sections (C, D) concern the early life stages of the prominent fishes in the waters around the Cook plant. There were eight larval fish species captured during field monitoring activities in 1973-1974. Each of these species is discussed in detail, with a description of its spatial (horizontal and vertical) and temporal (seasonal and diel) distribution. Extensive sets of length-frequency histograms documented what sizes of larvae were collected with depth, season and diel period. A final statement about potential entrainment impact was made about each species based on field data.

The entrainment section (D) gives data on the concentrations and total number of larval fish passing through Cook plant condensors. Sampling was negligible during 1973 and sporadic in 1974; however, different species of fish larvae were entrained. A comparison of the length-frequency distribution of alewives and rainbow smelt caught in field collections and those entrained was made. This comparison was made to ascertain if the plant was just cropping the small newly-hatched fish larvae or entraining larvae with the same size range as that observed in field samples.

These data will form the preoperational data base against which future data will be compared to determine any impacts the Cook plant may be having on Lake Michigan fish populations. We hope this report will serve as a documentation of the life history of many fishes in the inshore waters of the lake. Also we hope it will aid present and future scientists with the design of similar studies and with decisions regarding siting of any structure or intake with potential for impacting Lake Michigan fishes.

SECTION A

EXPERIMENTAL DESIGN AND STATISTICAL METHODS FOR MONITORING FISH POPULATIONS

INTRODUCTION

Initiation of on-line operation of Unit 1 at the Donald C. Cook Nuclear Plant in early months of 1975 signaled the end of preoperational environmental studies at the plant. Data collected on fish populations during 1973-1974 comprise the preoperational data base. These data will later be compared to operational data to evaluate potential impacts of Cook Plant cooling water use on the inshore fish populations of Lake Michigan.

We elected to monitor adult and juvenile fish populations by use of abundance indexes developed for three types of sampling gear: seines, trawls and gill nets. The index used was catch-per-unit-effort, and we assumed that for each gear, catch-per-unit-effort was proportional to the abundance of fish in the spatial and temporal region of the sample. Three gear types were used to sample the variety of life stages and sizes of fish species in the study areas. Sampling with each gear type should be considered a separate and distinct experiment since each gear is subject to different biases (Jude et al. 1975). However, we assumed that bias of each gear remained constant over time and sampling areas. Units of fishing effort for each gear were standardized for each sample and month of fishing (see SECTION B - METHODS). The combination of constant bias and standard units of effort provided assurance that catch-per-unit-effort was a reliable index of abundance for any fish species in the study area (Ricker 1975).

Increased emphasis was placed on analysis of variance (ANOVA) for statistical testing of fish population data, relative to analysis of 1973 data. We expanded use of ANOVA to portions of seine and gill net data, examined more critically the assumptions of ANOVA and investigated more fully our use of transformations. Where ANOVA could not be used due to failure to approximate assumptions, we used nonparametric tests that were different from those used for analysis of 1973 data (Jude et al. 1975). The change in nonparametric testing improved our ability to detect changes in fish abundance. As in the 1973 report (Jude et al. 1975) statistical testing of fish population changes was confined to the five most abundant species in field samples: spottail shiner, alewife, rainbow smelt, yellow perch and trout-perch.

This section concludes with a discussion of the ability of the various statistical procedures to detect fish population changes in the study areas. The discussion includes suggestions of alternative statistical techniques and improvements to current techniques in order to increase the power and efficiency of the data analysis, given the established sampling program.

ANALYSIS OF VARIANCE

The experimental design of the field sampling program for trawls, seines and gill nets fits a full factorial Model I (fixed effects) ANOVA with equal cell sizes (balanced design) (Sokal and Rohlf 1969). Factors of the ANOVA models were chosen to reflect major items of interest or expected major sources of variation in fish catch. Factors used in this study refer to temporal and spatial location of fish catch.

Three temporal factors were included in the ANOVA models. TIME of day with two levels (day, night) was designed to account for diel fluctuations in fish behavior and migration into and out of the sampling areas. MONTH of year was calculated to monitor seasonal fluctuations in fish abundance. (Note that not all 12 levels of the MONTH factor were used due to weather restraints on the field sampling program.) The third temporal factor YEAR was used to explore long-term variations in fish catch with particular consideration to comparison of preoperational and operational catch values. Current ANOVAs contain only 2 yr of preoperational data (1973-1974).

Factors involving spatial location refer specifically to stations frequented to collect field samples. For beach seines, three stations (A, B, F) comprised three levels of the single factor STATION (see SECTION B - METHODS for station descriptions). For both gill nets and trawls four stations (C, D, G, H) were categorized into two factors with two levels each; DEPTH (6 m, 9 m) and AREA (Cook Plant, Warren Dunes). Levels of the DEPTH factor correlate with discharge and intake structure depths; whereas two AREAs allow comparison of a treatment area (Cook Plant) with a reference area (Warren Dunes).

The factorial design of ANOVA is capable of testing differences in levels of main factors and interaction effects between main factors. These tests are independent planned comparisons (Steel and Torrie 1960). Formally each comparison is a test of a specific null hypothesis (H_o) which states that there is no significant difference between levels of the factor in question (or that there is no significant interaction among the factors in question.) A specific nominal Type I error probability (α) is assigned to each test; α is the probability that the null hypothesis will be rejected when it is in fact true. For ANOVA testing of fish abundance indexes, we set $\alpha = 0.01$. The converse Type II error probability (α) is the probability that the null hypothesis will be accepted when in fact a specific alternative hypothesis is true. By specifying both error probabilities α and β, it is possible to determine the least detectable true change (LDTC) for the ANOVA. The LDTC is a measure of sensitivity or ability of ANOVA to detect true differences between levels of a factor.

One other feature of factorial balanced ANOVA is its robustness to departures from assumptions. For the true α and β of an ANOVA to be exactly equal to the nominal α and β specified by the data analyst, assumptions of the ANOVA design must be met exactly. However factorial balanced ANOVA is particularly robust compared to imbalanced or non-factorial ANOVAs, and

moderate departures from assumptions will not invalidate results.

Assumptions of ANOVA

Assumptions necessary for strictly valid ANOVA arise from mathematical conditions under which ANOVA was derived. Whether or not data meet ANOVA assumptions can be inferred by evaluating the following set of propositions where residuals are developed from observed values by subtracting the cell mean:

1) Are the residuals from a normally distributed population?
2) Are the residuals homoscedastic, that is, do residuals have equal variances for all partitions of the data?
3) Are observations mutually independent?

In practice these propositions are met usually only approximately, and in general, minor deviations from assumptions affect results only slightly. However, degree of departure from exact ANOVA values depends on severity of the violation and robustness of the specific experimental design in relation to the specific assumption. These propositions may be tested independently, but they represent a set of highly interrelated characteristics of data. Thus effects of any violations may be summated in a non-obvious manner and specific effects may in fact ameliorate or exacerbate one another. In practice experimental design and data handling should reduce the violation of assumptions thereby insuring that ANOVA values are approximately correct and results valid. For further discussion see Eisenhart (1947), Cochran (1947), Chapter 10 of Scheffe (1959), Chapter 13 of Sokal and Rohlf (1969) and Section 7.15 of Steel and Torrie (1960).

Assumption of normality of residuals is required in order to obtain accurate probability values for α and β. However, Model I ANOVA is generally robust for this assumption, meaning that moderate departures from normality will not seriously alter α and β levels. Assumption of normality pertains to the condition that there is a true mean and only random error associated with observations in any cell of the ANOVA design.

Assumption of homoscedasticity for ANOVA is required due to use of a pooled error estimate for mean-square error (MSE). This assumption requires each cell of the factorial design to have a common variance. If the assumption is violated the pooled error estimate will be an overestimate for certain tests and an underestimate for others, thus altering α and β levels of the various F-tests of ANOVA.

Independence within ANOVA is related to assumption of random sampling. Validity of most analysis designs, including ANOVA, depends on random sampling. Violation of this assumption can have serious effects on inferences about means, and may invalidate ANOVA results.

Testing ANOVA Assumptions

For trawls and seines the following procedures were used to examine data for assumptions of normality and homoscedasticity. (Due to lack of replication gill net data were treated differently. Details are presented under the heading GILL NETS.) Results of testing of assumptions for each gear are presented and discussed later.

Two procedures were used to test whether residuals were from a normally distributed population. Residuals were partitioned by main factor levels and frequency histograms for each partition examined. In addition total residuals were subjected to the Lilliefors test (Conover 1971), which is a Kolmogorov-Smirnov one-sample test (Siegel 1956) modified to test for general normality (Lilliefors 1967). Testing was performed on the Michigan Interactive Data Analysis System (MIDAS) (Fox and Guire 1973) using a procedure suggested by the Statistical Research Laboratory (1975a). Each test statistic (D), developed as the maximum difference between the cumulative distribution functions (Sokal and Rohlf 1969) of a set of residuals and a theoretical normal distribution, was compared to the Lilliefors critical difference (D_c) taken from tables or the large-sample approximation given by Lilliefors (1967) for $\alpha = 0.01$. Test statistic values that exceeded the Lilliefors critical difference indicated that residuals were not from a normally distributed population. However values of the test statistic that were close to D_c indicated a better approximation to the normal distribution than values that were much higher than D_c. Lilliefors test results were examined under the consideration that the test is extremely powerful in detecting non-normality and that ANOVA F-tests are particularly robust against non-normality.

To test for homoscedasticity, residuals were plotted against cell means and against levels of each main factor. Visual inspection of these plots was preferred to the more exact Box's test of variance (Box 1949) because Box's method may be invalidated by slight departures from normality (Box 1953, Box and Anderson 1955).

Data which approximated the assumptions of normality and homoscedasticity were subjected to additional testing to explore the more serious assumption of independence. For replicate sampling, each replicate pair was scored as '+' if the catch of the second sample exceeded the first, '-' if the first sample exceeded the second, and '0' if the two samples were equal. If replicate observations were independent the number of +s should equal the number of -s. Data matrices were partitioned by all combinations of factor-levels and binomial tests performed to test the null hypothesis that the number of +s equaled the number of -s. When the null hypothesis is true, 5% of the tests should be rejected at $\alpha = 0.05$ and 1% of the tests should be rejected at $\alpha = 0.01$. Binomial test statistics were compared with table values for sample sizes $n \leq 25$ or with the normal approximation for samples $n > 25$ (Zar 1974). Note that for $\alpha = .01$, tests were not possible for $n < 8$; for $\alpha = 0.05$, tests were not possible for $n < 6$.

All rejected tests were considered together to determine if one particular factor was responsible for most rejections. It should be noted that binomial tests performed in this fashion were not independent of one another, but when considered in total they provided an indication of any lack of independence of replicate observations.

Transformations

For 1973 ANOVAs (Jude et al. 1975) raw catch data were transformed by $\log_{10}$(catch + 1) to induce normality and render data more amenable to parametric analysis via ANOVA. For the 1973-1974 combined data, considerable effort was expended to verify that log transformation was indeed an improvement over raw catch data. Another empirical transformation, square root (catch + 1/2), was examined to determine if its characteristics might prove better in terms of normalizing catch data and equalizing variances. Testing of assumptions for all three forms of data (raw catch, log transformation and square root transformation) was performed for all three gear types (trawl, seine and gill net) for the five most abundant species over appropriate levels of ANOVA factors.

Examination of transformed and untransformed data for assumptions of normality and homoscedasticity revealed that the log transformation was superior to both the square root transformation and raw catch data in meeting ANOVA assumptions. ANOVAs used to test for fish population changes were based on the transformed values $\log_{10}$(catch + 1) and unless otherwise indicated, ANOVA results and results of assumption testing pertain to log-transformed data. Note that graphs of ANOVA interactions contain back-transformed means of log-transformed data. These are equivalent to geometric means of original data. Geometric means are often approximately half the magnitude of arithmetic means of the same data, depending on the distribution of data values. While log transformation preserves rank order of individual observations it does not always preserve rank order of cell means. Natrella (1963) presented an example where rank order of two cell means was reversed when log transformation was applied to individual observations. Such cases indicate the effect of transformation on the distribution of data values and consequent ability to meet parametric assumptions.

Interaction and Additivity

Factorial ANOVA allows independent tests of interaction effects as well as main effects. If all interaction effects are statistically nonsignificant, the ANOVA describes an additive model. Each main effect may be interpreted independently of effects due to other main factors, resulting in a simple and concise description of the model. The term additivity is applicable because the total effect on each cell of the ANOVA design is simply the sum of all main effects on that cell.

Significant interactions in high-order factorial ANOVAs increase the complexity of interpreting results. Each main factor involved in

significant interaction must be discussed with reference to specific levels of other factors included in that interaction. Significant interaction implies that the effect of a main factor differs according to the levels of interacting factors. Lack of additivity means that the total effect on any cell of the ANOVA design is the sum of the main effects plus adjustments according to the specific levels of interacting factors for that cell.

Power and Least Detectable True Change

Given that a particular ANOVA meets parametric assumptions, it is possible to calculate a least detectable true change (LDTC) that will indicate the power of the ANOVA to detect alternate hypotheses. The LDTC is the minimum difference in mean levels that can be detected by ANOVA and is a measure of sensitivity of design.

The following formula for LDTC (δ) was derived from Sokal and Rohlf (1969) and presented in Jude et al. (1975).

$$\delta = s(2/n)^{1/2} \, (t_{\alpha[\nu]} + t_{2(1-P)[\nu]})$$

where:

- s = within-cell error standard deviation of ANOVA; s is the square root of the error mean square
- n = number of observations in each of two groups being compared (in our analyses, groups compared had equal numbers of observations)
- α = significance level (Type I error probability)
- t = Student's t
- ν = degrees of freedom
- P = Power = probability that a true difference will be judged significant by ANOVA = 1 - β
- β = Type II error probability.

Since this formula was applied to log-transformed data, it was necessary to back transform the LDTC in order to express results as changes in numbers of fish. Derivation of the back transformation was given in Jude et al. (1975). For any LDTC (δ) based on log-transformed data, the least detectable true change expressed as the quantity "mean number of fish per catch plus one" is 10^{δ}, which is the ratio between quantities being compared. Thus ANOVA will detect as significant any change in fish abundance by a factor of 10^{δ} or greater. For example, two means x and y will be detected as significantly different if $y \geq 10^{\delta}x$ or if $y \leq x/10^{\delta}$. Results of power analyses on ANOVAs are presented as values of the ratio 10^{δ} as a function of levels of α and P (see Tables A5, A9 and A10). For additional discussion regarding power calculations plus an example calculation, see pages 13-18 of Jude et al. (1975).

Missing Samples in ANOVA

In addition to samples missing due to inclement weather (in which case months were dropped from the ANOVA matrix), there were a few occasions when a sample within the data matrix was lost due to problems unrelated to ANOVA factors. For these cases where loss of a sample may be considered a random event the unbalanced data were subjected to an unweighted-means analysis as described by Fox (1973). This method involved substituting the cell mean for the missing sample (for trawl and seine data the cell mean was the value of the replicate sample) and performing a balanced design analysis using the BMD8V program provided by the Statistical Research Laboratory of the University of Michigan (Statistical Research Laboratory 1975b). The output of this program was adjusted to account for use of cell means in place of missing samples. Every numerator sum of squares was multiplied by the ratio n_h/N (where n_h is harmonic mean cell size and N is balanced cell size). The number of substituted observations was then subtracted from degrees of freedom of appropriate denominator sums of squares. F-ratios and tests of significance were performed and interpreted as usual. Note that cell means were substituted for missing samples for testing of ANOVA assumptions as well as actual ANOVA calculations.

TRAWLS

The trawl data matrix was designed to fit a five-way completely crossed factorial ANOVA with two replicates per cell. Temporal factors of TIME, MONTH and YEAR were complemented by spatial factors AREA and DEPTH. The MONTH factor was reduced to seven levels (April through October) due to weather-restricted sampling. Within the 7-mo period there were two samples lost due to random factors: a day trawl (replicate 2) at station G in April 1973 and a night trawl (replicate 2) at station G in September 1973. These two missing values were replaced by cell means (replicate values) as discussed previously.

Distributional properties of 1973-1974 trawl catch data (Table A1) differed slightly from those of 1973 trawl catch data (see Table A1 in Jude et al. 1975). Alewife mean catch increased with addition of 1974 data to 1973 data while mean catch of rainbow smelt, yellow perch and trout-perch declined. Percentage of zero catches for 1973-1974 increased over 1973 values for spottail shiner, rainbow smelt, yellow perch and trout-perch. Zero-catch values for yellow perch and trout-perch were especially high for the 7-mo period (April through October). Deletion of April and May from the data matrix reduced the percentage of zero catches for these two species. High values of the coefficient of dispersion indicated contagious distributions (Sokal and Rohlf 1969), characteristic of sampled organisms distributed in scattered groups.

Testing for ANOVA Assumption

Results of Lilliefors test for normality of residuals (Table A2) revealed that although none of the sets of residuals were accepted as

Table A1. Comparison of distributional properties of 1973-74 sample data for the five most abundant fish species caught in standard series trawls, gill nets and seines at Cook Plant study areas, southeastern Lake Michigan.

Gear	Sample Size (n)	Mean Catch ($\bar{x}$)	Standard Deviation (s)	Coef. of Variation $(s/\bar{x})\cdot 100$	Coef. of Dispersion $(s^2/\bar{x})$	% Zero Data
TRAWL[1] (APR-OCT)						
Spottail shiner	224	27.7	51.5	186	96	20.5
Alewife	224	123.6	269.3	218	587	13.4
Rainbow smelt	224	83.0	208.1	251	521	14.3
Yellow perch	224	8.8	18.1	206	37	41.1
Trout-perch	224	20.0	45.7	228	104	26.3
TRAWL[2] (JUN-OCT)						
Yellow perch	160	11.9	20.5	172	35	34.4
Trout-perch	160	26.4	52.7	200	105	21.3
GILL NET (MAR-OCT)						
Spottail shiner	128	47.9	83.0	173	144	18.0
Alewife	128	160.2	233.1	139	311	10.2
Rainbow smelt	128	6.2	13.0	209	27	45.3
Yellow perch	128	17.2	33.6	195	66	30.5
Trout-perch	128	3.7	10.8	291	32	58.6
SEINE[2] (APR-OCT)						
Spottail shiner	168	193.0	475.7	247	1173	12.5
Alewife	168	1051.1	4126.8	393	16203	24.4
Rainbow smelt	168	16.6	82.1	495	406	70.8
Yellow perch	168	23.7	82.7	348	288	63.7
Trout-perch	168	0.6	2.2	372	8	85.1

[1] Cell mean (replicate) values substituted for two missing observations.

[2] Cell mean (replicate) value substituted for one missing observation.

Table A2. Values of the Lilliefors test statistic for normality of residuals from log-transformed trawl catch data for the five most abundant species in Cook Plant study areas, 1973-1974. Residuals were accepted as samples from a normally distributed population if test statistic value (D) was less than the Lilliefors critical difference (D_c). Lilliefors critical difference values were chosen for α = 0.01. n = sample size.

Months	Species	Lilliefors Test Statistic (D)
APR-OCT		
n = 224	Spottail shiner	0.1116
D_c = 0.0689	Alewife	0.0903
	Rainbow smelt	0.1045
	Yellow perch	0.1875
	Trout-perch	0.1339
JUN-OCT		
n = 160	Yellow perch	0.1375
D_c = 0.0815	Trout-perch	0.1058

normally distributed, test statistic values were close to Lilliefors critical difference values. Test statistic values indicated that for yellow perch and trout-perch, data for the period June through October were more nearly normally distributed than data for the period April through October. Examination of histograms of residuals revealed no evidence of serious non-normality.

Scatterplots of residuals versus factor levels showed no evidence of serious heterogeneity of variance. Plots of residuals versus cell means also demonstrated reasonable homoscedasticity although an interesting phenomenon that was noted in Jude et al. (1975) appeared in 1973-1974 data. Alewife and rainbow smelt residuals below cell mean values of 1.9 on log-transformed scale (geometric means of about 80 fish) had distinctly greater variance than residuals above that cell mean boundary. (This dichotomy was not noted for spottail shiner even though cell means of 1.9 were within the range of cell means for that species.) Plots of cell means against main factor levels indicated that high cell means were not restricted to any segment of ANOVA design but occurred throughout the data. Thus this phenomenon does not contribute to heteroscedasticity between factor levels and will not bias ANOVA results. The pattern is probably due to interaction of fish distribution and fishing characteristics of trawl sampling.

Binomial testing of +:- ratios of replicate samples in data chosen for ANOVA revealed no evidence of lack of independence. Percentage of binomial tests rejected was close to that expected due to simple Type I (α) error

(Table A3). Examination of all rejected binomial tests disclosed two tests involving levels of main factors MONTH and YEAR. The ratio of +:- for the month of June was 45:23 (significant, α=0.01), indicating a tendency for the second trawl haul to exceed the first. This trend was more pronounced for Cook Plant replicates (ratio 27:8, significant, α=0.01) than for Warren Dunes replicates (ratio 18:15, not significant, α=0.05). Ratios for other months were not significantly different from 1:1 (α=0.05). The ratio of +:- for 1974 was 107:78 (significant, α=0.05), also indicative of a tendency for the second trawl haul to exceed the first. This trend also was more pronounced for Cook Plant replicates (ratio 62:38, significant, α=0.05) than for Warren Dunes replicates (ratio 51:49, not significant, α=0.05). The significant test results for Cook Plant replicates in June and 1974 were probably due to interaction of prevailing wind and currents and directional pattern of trawl hauls as discussed in Jude et al. (1975). Such interaction increases the variance of replicate observations and reduces power of ANOVA but does not bias results.

Table A3. Results of binomial tests on +:- ratios of differences between second and first replicates of trawl catch data used in ANOVA. Total number of tests represents all possible tests for data partitioned by all levels of each main factor of ANOVA where sample size was adequate.

Significance Level (α)	Total Number of Tests	Number of Tests Rejected	Percentage of Tests Rejected	Expected Percentage of Tests Rejected
0.01	823	13	1.58	1.00
0.05	1075	46	4.28	5.00

In summary the following ANOVA design was accepted as approximately meeting the parametric assumptions of the model:

Factor	Number of Levels	Levels
1. TIME of day	2	day, night
2. MONTH	7 (alewife, spottail shiner, rainbow smelt)	April-October
	5 (yellow perch, trout-perch)	June-October
3. YEAR	2	1973, 1974
4. DEPTH	2	6 m, 9 m
5. AREA	2	Cook Plant, Warren Dunes

Restriction of yellow perch and trout-perch designs to 5 mo sacrificed 2 mo of data to insure adherence of data to ANOVA assumption of normality and improve confidence in validity of test results.

Additivity

Interpretation of main effects for spottail shiner, alewife and rainbow smelt ANOVAs was complicated by significant (α=0.01) third-order interactions for all main factors (Table A4). Discussion of results for each main factor must be tempered by consideration of levels of at least two other interacting factors. Thus it may be difficult to explain any future changes in fish abundance in relation to simple treatment-reference (AREA) or preoperational-operational (YEAR) effects.

Table A4. Comparison of highest order of significant (α = 0.01) interaction between ANOVA factors for the five most abundant species taken in trawl catches during 1973-1974 in Cook Plant study areas. Values are based on five-way ANOVAs, results of which are presented elsewhere in this report.

SPECIES	YEAR	MONTH	AREA	DEPTH	TIME
Spottail shiner	3rd	3rd	3rd	3rd	3rd
Alewife	3rd	3rd	3rd	3rd	3rd
Rainbow smelt	3rd	3rd	3rd	3rd	3rd
Yellow perch	2nd	2nd	none	1st	2nd
Trout-perch	2nd	2nd	none	2nd	2nd

The situation for yellow perch and trout-perch was less complex. For both species AREA did not enter into any significant interactions. Other factors were involved in at most second-order interactions. Main effects related to AREA were insignificant (α=0.01) for trout-perch and lack of interaction will allow a simple and straightforward interpretation of any significant differences or interactions involving AREA that appear in operational ANOVAs.

Power Analysis

Least detectable true changes (LDTC) calculated for trawl ANOVAs (Table A5) are slightly higher than values appearing in Tables A3-A7 of Jude

Table A5. Least detectable true change (LDTC) in geometric mean abundance of the five most abundant species caught in trawls at Cook Plant study areas, southeastern Lake Michigan. These are values of the ratio 10^{δ}, where δ is the least detectable true change in arithmetic mean abundance of log-transformed catch. Values are given as functions of Type I error (α) and power. Comparison is of 2 yr preoperational sampling to 2 yr operational sampling at one AREA (based on the assumptions that within-cell error standard deviation remains the same through 1975-1976 as it was in 1973-1974 and does not differ between AREAs). Each LDTC is expressed as the ratio of the operational value to the preoperational value of the quantity "mean number per trawl haul plus one". n = sample size. ν= degrees of freedom.

Spottail shiner (n=112, ν=224)

α	Power .90	Power .95
.01	1.41	1.46
.02	1.38	1.43
.05	1.34	1.38
.10	1.30	1.34

Alewife (n=112, ν=224)

α	Power .90	Power .95
.01	1.69	1.78
.02	1.64	1.72
.05	1.56	1.63
.10	1.49	1.57

Rainbow smelt (n=112, ν=224)

α	Power .90	Power .95
.01	1.47	1.52
.02	1.43	1.48
.05	1.38	1.43
.10	1.34	1.39

Yellow perch (n=80, ν=160)

α	Power .90	Power .95
.01	1.66	1.74
.02	1.60	1.69
.05	1.53	1.60
.10	1.46	1.54

Trout-perch (n=80, ν=160)

α	Power .90	Power .95
.01	1.58	1.65
.02	1.53	1.60
.05	1.47	1.53
.10	1.41	1.47

et al. (1975) which compared 2 yr preoperational to 2 yr operational data. While differences are not large, they do indicate that 1973-1974 ANOVAs are slightly less powerful than was anticipated in Jude et al. (1975). Loss of sensitivity was due solely to increased mean-square error (MSE) in 1973-1974 ANOVAs over that calculated for 1973 alone (Table A6). All other parameters in the power analysis have remained constant. Increase in MSE is a result of differences in fish catch distributions between 1973 and 1974.

Table A6. Comparison of mean-square error (MSE) values of 1973 to 1973-1974 trawl ANOVAs.

SPECIES	1973	1973-1974
Spottail shiner	0.06238	0.08337
Alewife	0.11924	0.19462
Rainbow smelt	0.07949	0.10318
Yellow perch	0.09679	0.12663
Trout-perch	0.09465	0.10389

SEINES

The experimental design for seine data was a four-way completely crossed factorial ANOVA with two replicates per cell. Temporal factors of

TIME, MONTH, and YEAR were complemented by the spatial factor STATION with three levels (A, B, F) corresponding to three seining stations in the study areas. The MONTH factor was reduced to seven levels (April through October) due to weather-restricted sampling. Within the 7-mo period there was one missing sample due to factors unrelated to the experimental design: a day seine (replicate 1) at station F in July 1973. That missing value was replaced by the cell mean (replicate value) as discussed previously.

Distributional properties of 1973-1974 seine catch data (Table A1) differed somewhat from 1973 seine catch data (see Table A1, Jude et al. 1975). Mean catch of alewife and rainbow smelt decreased sharply while spottail shiner mean catch increased slightly. Mean catch of yellow perch in 1973-1974 almost tripled over the 1973 value and standard deviation also increased drastically. Standard deviations of catch for other species showed relatively minor changes. Percentage of zero data also changed little, values for rainbow smelt, yellow perch and trout-perch remaining very high. High values of the coefficient of dispersion indicated contagious distributions (Sokal and Rohlf 1969).

Testing ANOVA Assumptions

Results of Lilliefors test for normality of residuals are presented in Table A7. Although none of the sets of residuals were accepted as normally distributed, test statistic values for spottail shiner and alewife were close to the Lilliefors critical difference. Examination of histograms of residuals confirmed that spottail shiner and alewife residuals were approximately normally distributed. Histograms of residuals of rainbow smelt, yellow perch and trout-perch exhibited extreme peakedness (leptokurtosis) as a result of high percentage of zero data.

Table A7. Values of the Lilliefors test statistic for normality of residuals from log-transformed seine catch data for the five most abundant species in Cook Plant study areas, April through October, 1973-1974. Residuals were accepted as a sample from a normally distributed population if test statistic value (D) was less than Lilliefors critical difference (D_c). D_c = 0.07954 for sample size n = 168 at α = 0.01

SPECIES	Lilliefors Test Statistic (D)
Spottail shiner	0.09411
Alewife	0.13264
Rainbow smelt	0.30952
Yellow perch	0.30357
Trout-perch	0.39881

Scatterplots of residuals versus cell means showed no evidence of heteroscedasticity except for yellow perch, which exhibited greater variability at intermediate cell means than at lower or higher cell means. Plots of residuals versus factor levels showed reasonable homogeneity of variance for spottail shiner and alewife, but serious heteroscedasticity for the other three species due to excessive zero observations.

Due to failure to approximate assumptions of normality and homoscedasticity, rainbow smelt, yellow perch and trout-perch data were excluded from ANOVA. Binomial testing for independence of replicates was confined to spottail shiner and alewife data.

For spottail shiner there was no evidence of lack of independence between replicates. Only one of 55 tests (1.82%) was rejected at α=0.05. The rejected test indicated a tendency for the first seine haul to exceed the second in the month of October, with a +:- ratio of 1:10 (significant, α=0.05). None of 31 tests performed at α=0.01 were rejected.

Binomial testing of independence for alewife produced mixed results. None of 29 tests performed at α=0.01 were rejected but there were three rejections out of 46 tests (6.52%) at α=0.05. This is slightly more than 5% expected rejections. Two rejected tests involved major levels of the ANOVA design and all three indicated a tendency for the second seine haul to exceed the first. The ratio of +:- for all alewife seine catches was 42:23. The ratio for day seine hauls was 20:9. The final rejected test was for seine hauls in May 1974, with a ratio of 6:0 (all significant, α=0.05). These results may be simply an artifact of the data or indicative of a true dependence of alewife catch on replicate seine hauls. Binomial testing of operational data should enable a decision between these two possiblities.

In summary, the ANOVA design utilized for spottail shiner and alewife for seines was as follows:

Factor	Number of Levels	Levels
1. TIME of day	2	day, night
2. MONTH	7	April-October
3. YEAR	2	1973, 1974
4. STATION	3	A, B, F

Additivity

Interpretation of main effects for alewife seine ANOVA was complicated by significant (α=0.01) third-order interactions for all main factors (Table A8). Explanation of fish abundance changes in relation to treatment-reference (STATION) and preoperational-operational (YEAR) effects must include effects due to levels of interacting factors.

Table A8. Comparison of highest order of significant (α = 0.01) interaction between ANOVA factors for spottail shiner and alewife in 1973-1974 seine catches from Cook Plant study areas. Values are based on four-way ANOVAs, results of which are presented elsewhere in this report.

SPECIES	YEAR	MONTH	STATION	TIME
Spottail shiner	2nd	2nd	none	2nd
Alewife	3rd	3rd	3rd	3rd

For spottail shiner ANOVA, the main factor STATION was not involved in any significant interactions, although other factors entered into significant second-order interactions. Main effects related to STATION were not significant (α=0.01) for spottail shiner and lack of interaction will allow straightforward interpretation of any significant differences or interactions involving STATION that appear in operational ANOVAs.

Power Analysis

Least detectable true changes (LDTC) calculated for seine ANOVAs (Table A9) were distinctly larger than LDTC values for trawl ANOVAs (Table A5). Changes in fish abundance that would be judged significant in trawl ANOVA would not be detected in seine ANOVA . Lower sample size (n) and resultant fewer degrees of freedom (ν) were major reasons for relative lack of power in seine ANOVAs. Power analysis for seines was based on

comparison of 2 preoperational to 2 operational yr for data from one STATION, while trawl power analysis was based on data from one AREA (two stations). A contributing factor for spottail shiner was that mean-square error (MSE) for seine ANOVA (0.26680) was more than three times larger than MSE for trawl ANOVA (0.08337). For alewife, MSE for trawl ANOVA (0.19462) was slightly larger than MSE for seine ANOVA (0.18800).

Table A9. Least detectable true change (LDTC) in geometric mean abundance of spottail shiner and alewife caught in seines at Cook Plant study areas, southeastern Lake Michigan. These are values of the ratio 10^{δ}, where δ is the least detectable true change in arithmetic mean abundance of log-transformed catch. Values are given as functions of Type I error (α) and power. Comparison is of 2 yr preoperational sampling to 2 yr operational sampling at one station (based on the assumptions that within-cell error standard deviation remains the same through 1975-1976 as it was in 1973-1974 and does not differ between the three stations). Each LDTC is expressed as the quantity "mean number per seine haul plus one". n = sample size. ν = degrees of freedom.

Spottail shiner ($n=112$, $\nu=224$)			Alewife ($n=112$, $\nu=224$)		
	Power			Power	
α	.90	.95	α	.90	.95
.01	2.40	2.60	.01	2.08	2.23
.02	2.26	2.46	.02	1.99	2.13
.05	2.08	2.26	.05	1.85	1.98
.10	1.94	2.10	.10	1.74	1.87

GILL NETS

The gill net data matrix was designed to fit a five-way completely crossed factorial ANOVA similar to trawl ANOVA design, but with just one observation per cell. Temporal factors of TIME, MONTH and YEAR were complemented by spatial factors AREA and DEPTH. The MONTH factor was limited to eight levels (March through October) due to weather-restricted sampling. There were no missing samples within this period.

Distributional properties of 1973-1974 gill net catch data (Table A1) were similar to those of 1973 gill net catch data (see Table A1, Jude et al. 1975). Mean catch for all species declined slightly but this may be due to addition of March values to the data; 1973 values were calculated for the period April though October. Percentage of zero data was high for rainbow smelt, yellow perch and trout-perch. High values of the coefficient of dispersion indicated contagious distributions (Sokal and Rohlf 1969).

Testing ANOVA Assumptions

Residuals were not calculated for gill net data. Instead, testing for normality and homoscedasticity was applied directly to catch values partitioned by levels of all main factors into 16 groups for each species, each group comprising catch values of one level of a main factor. Testing for independence could not be accomplished.

Each of the 16 groups of observations for each species was subjected to the Lilliefors test for normality. For spottail shiner 13 of the groups were accepted as samples from a normal distribution, and 10 groups were accepted for alewife. For rainbow smelt, yellow perch and trout-perch less than half of the 16 groups were accepted as normally distributed.

Histograms of the 16 groups of observations for each species demonstrated extreme peakedness (leptokurtosis) for parts of the rainbow smelt, yellow perch and trout-perch data. Examination of histograms for amount of scatter (variance) indicated extreme heteroscedasticity for all species except spottail shiner. Due to failure to approximate assumptions of normality and homoscedasticity all species except spottail shiner were excluded from ANOVA.

In summary the ANOVA design utilized for spottail shiner in gill nets was as follows:

Factor	Number of Levels	Levels
1. TIME of day	2	day, night
2. MONTH	8	March-October
3. YEAR	2	1973, 1974
4. DEPTH	2	6 m, 9 m
5. AREA	2	Cook Plant, Warren Dunes

Since there was just one observation per cell, there was no term in the model for direct calculation of mean square error (MSE). Examination of high-order interaction terms of trawl ANOVAs revealed each fourth-order interaction to be nonsignificant. Thus for the gill net ANOVA, the fourth-order interaction was assumed to be zero and its mean square used as an estimate of MSE. Note that use of a pooled mean square estimate (Sokal and Rohlf 1969), utilizing third-order interaction terms, was contraindicated by significant third-order interactions in trawl ANOVAs.

Additivity

The fourth-order interaction term was assumed nonsignificant. All main factors of the spottail shiner ANOVA were involved in significant

second-order interactions, except DEPTH, which entered into a first-order interaction. Again, presence of interactions complicated explanations of main effect results.

Power Analysis

Least detectable true changes (LDTC) calculated for the spottail shiner gill net ANOVA (Table A10) were close to but slightly higher than LDTC values for spottail shiner in trawl ANOVA, indicating that gill net ANOVA was somewhat less powerful than trawl ANOVA. Note that while the spottail shiner MSE for gill nets (0.06052) was less than the value for trawl samples (0.08337), gill net LDTC values increased because of lower sample size and fewer degrees of freedom, both a result of lack of replication in the data matrix.

Table A10. Least detectable true change (LDTC) in geometric mean abundance of spottail shiner caught in gill nets at Cook Plant study areas, southeastern Lake Michigan. These are values of the ratio 10^{δ}, where δ is the least detectable true change in arithmetic mean abundance of log-transformed catch. Values are given as functions of Type I error (α) and power. Comparison is of 2 yr preoperational sampling to 2 yr operational sampling at one AREA (based on the assumptions that within-cell error standard deviation remains the same through 1975-1976 as it was in 1973-1974 and does not differ between AREAs.) Each LDTC is expressed as the quantity "mean number per gill net plus one". n = sample size. ν = degrees of freedom.

Spottail shiner ($n=64$, $\nu=7$)		
	Power	
α	.90	.95
.01	1.64	1.72
.02	1.56	1.63
.05	1.46	1.53
.10	1.39	1.46

NONPARAMETRIC ANALYSIS

Failure of gill net data for alewife, rainbow smelt, yellow perch and trout-perch to meet parametric assumptions of ANOVA prompted statistical analysis by means of nonparametric tests. The two nonparametric tests used on 1973 data (Jude et al. 1975), the Mann-Whitney test and the Kruskal-Wallis test, are based on unrelated samples (Conover 1971). Because of the structure of the tests as performed on gill net and seine data of

1973, tests for main factors were not independent. Highly significant differences between MONTHs reduced the ability of these tests to detect differences between other factors.

Nonparametric tests of 1973-1974 data were based on paired samples, pairing by MONTHs. The two procedures used were the sign test and the Wilcoxon signed ranks test (Conover 1971). Both tests assume that samples are drawn from populations with a continuous distribution. Both tests operate on a set of differences between paired samples, created by subtracting values of one sample from corresponding values of the other sample. The sign test utilizes only the signs of these differences (positive or negative) to develop a test statistic. The Wilcoxon test incorporates a measure of magnitude by taking into account the rank order of differences (largest to smallest).

The structure of these related-sample tests, pairing by months, allows any significant differences between months to be accounted for when testing for significant differences across other factors. To insure independent tests of main factors YEAR, AREA, TIME and DEPTH, each factor was tested separately for every combination of levels of the other factors. Since MONTHs were used in pairing samples no testing of MONTH effects was performed. MONTH was assumed to be a significant factor. The structure of this testing procedure precludes testing for interactions although some indication of interaction may be gleaned from comparisons of results of main factor tests between levels of non-testing factors. Pairing by MONTHS completely masks any interactions involving the MONTH factor.

Gill net data were subjected to two-tailed tests at $\alpha = 0.01$. (Results appear in Tables B18, B30, B36 and B42.) While two-tailed tests detect significant differences between samples without regard to the direction of difference, significant differences noted in the data tables indicate which sample was "larger". For the sign test, the "larger" sample will be the one which contributes the larger value of each pair for the majority of paired values. For the Wilcoxon test the magnitude of differences between paired values must also be considered.

Type I error accepted for nonparametric tests ($\alpha = 0.10$) was larger than that used for ANOVA ($\alpha = 0.01$) in order to increase the power of the nonparametric tests. Nonparametric tests are less powerful than parametric tests when parametric assumptions are met, although as measured by power-efficiency, the sign and Wilcoxon tests compare favorably to parametric t-tests for small sample sizes as used here. Power-efficiency indicates the fraction of given sample size that a parametric test would require to achieve the same power as the nonparametric test achieves at given sample size. Siegel (1956) reported the sign test as 95% power-efficient at sample sizes of $n = 6$ and the Wilcoxon test as approximately 95% power-efficient for small samples, compared to parametric t-tests.

The assumption of continuous distributions precludes the possibility of tied values (zero differences) in paired data. However, tied values were common in gill net data and in such cases tied pairs were excluded from the test (Siegel 1956). This restricted the scope of the test to the set of untied pairs. In some cases so many ties occurred that sample size dropped from the maximum (12 pairs) to a level where the number of non-zero differences (untied pairs) was too low to establish a rejection region for the test. Such cases are reported as no test (NT).

SUMMARY AND CONCLUSIONS

Fish abundance data generated by the field sampling program at Cook Plant study areas will be used to evaluate potential impacts of the plant on fish populations in nearshore southeastern Lake Michigan. Statistical analyses applied to preoperational data allowed investigation of the ability of those techniques to detect significant changes in fish abundance and to assist in ascribing changes to either impacts of the Cook Plant or other causes.

Analysis of variance provided a comprehensive and powerful method for detecting changes in fish abundance. Testing of log-transformed data ($\log_{10}$[catch + 1]) for adherence to assumptions of ANOVA insured that assumptions were not seriously violated and results of analysis could be accepted as valid. Data which did not approximately meet assumptions were excluded from ANOVA. Note that for many forms of population distribution of data, an exact transformation can be developed, increasing the power of the analysis (Bartlett 1947). In particular since trawl data presented by Taylor (1953) was found to fit a negative binomial distribution, the transformation $\log_{10}$[catch + K/2] may be more appropriate to our trawl data (and possibly to seine and gill net data as well) than the empirical transformation $\log_{10}$[catch + 1]. This would require estimation of the exponent parameter K of the negative binomial distribution. Unless the parameter K is very much different from 2, the improvement, attributed to the use of the negative binomial transformation, would probably be slight.

Factorial design of ANOVA allows independent tests of main factors and their interactions, yielding important information concerning dependence of fish catch on temporal and spatial location. Two main factors are of predominant importance in detecting and attributing significant changes in fish abundance to either Cook Plant impacts or other causes. Patterns of results of main effect tests on factors YEAR and AREA/STATION (AREA for trawl and gill net ANOVAs, STATION for seine ANOVAs) can be useful in assigning significant changes to plant or non-plant effects (Table A11). If both YEAR and AREA/STATION main effects are nonsignificant in preoperational ANOVA (condition A, Table A11), operational results will provide definite criteria for ascribing changes to plant or non-plant effects. If YEAR is a significant main effect but AREA/STATION is nonsignificant in preoperational ANOVA (Condition B, Table A11), plant effects may be easily detected if AREA/STATION is significant in operational ANOVA; but multiple comparison tests (Cochran and Cox 1957, Scheffe 1959), and careful examination of plots

of geometric means of main effects and lower-order interactions for patterns or trends will be required to investigate differences between preoperational-operational YEARs. If YEAR is a nonsignificant main factor and AREA/STATION is significant in preoperational ANOVA (condition C, Table A11), non-plant effects may be readily identified if YEAR is a significant factor in operational ANOVA. However, testing for plant effects will require use of multiple comparison tests on levels of AREA/STATION. If both YEAR and AREA/STATION are significant main effects (condition D, Table A11), detection of both plant and non-plant effects will require use of multiple comparison tests in order to determine which levels of YEAR and AREA/STATION contribute to the significant effect.

Table A11. Summary of potential results of main effect tests on factors YEAR and AREA/STATION in preoperational (1973-1974) and preoperational-operational (1973-1976) ANOVAs, related to detection of Cook Plant environmental impacts. All interactions involving YEAR and AREA/STATION are assumed nonsignificant. NS = nonsignificant, SIG = significant.

	Preoperational ANOVA (1973-1974)		Preoperational-Operational ANOVA (1973-1976)		Operational
	YEAR	AREA/STATION	YEAR	AREA/STATION	Changes in Fish Abundance
A.	NS	NS	NS	NS	None detected
			SIG	NS	Non-plant effects
			NS	SIG	Plant effects
			SIG	SIG	Plant and non-plant effects
B.	SIG	NS	SIG	NS	None detected[1]
			SIG	SIG	Plant effects[1]
C.	NS	SIG	NS	SIG	None detected[2]
			SIG	SIG	Non-plant effects[2]
D.	SIG	SIG	SIG	SIG	None detected[1,2]

[1] Use multiple comparison tests to investigate operational differences between years.

[2] Use multiple comparison tests to investigate operational differences between AREAs/STATIONs.

The conditions summarized in Table A11 are simplified by assumption of nonsignificant interactions. Presence of significant interactions complicates explanation of main effect results. However, differences between interactions in preoperational and operational ANOVA can provide

additional information concerning plant and non-plant effects. In particular, if an interaction involving YEAR is nonsignificant in preoperational ANOVA but significant in operational ANOVA, some change in pattern of fish abundance between preoperational and operational years is indicated.

While significant interactions complicate interpretation of ANOVA results, they do not necessarily disrupt the basic conditions presented in Table A11. The balanced completely crossed factorial design incorporates interaction effects into main effects, since the levels of each main factor comprise all levels of every other factor. Thus some main effects may be interpreted as "overall" effects over and above interaction effects. Such interpretation of "overall" main effect requires critical examination of interactions, and may be invalidated by certain patterns of interaction. For example, significant interaction between factors YEAR and AREA/STATION may invalidate interpretation of main effect results as "overall" effects for those factors, because an interaction may indicate plant-induced shifts of fish abundance between AREAs/STATIONs over YEARs, even though main effects are not significant. In other cases, significant interactions involving YEAR, AREA or STATION may not preclude interpretation of main effects as "overall" effects, and main effect results may be compared to the conditions listed in Table A11. However, each case involving significant interactions must be thoroughly and carefully examined to prevent misinterpretation of ANOVA results.

A summary of actual results of preoperational ANOVAs (Table A12) reveals that potential to detect Cook Plant effects is good. Three ANOVAs (alewife in trawls and seines and spottail shiner in seines) fall under condition A (Table A11) and thus allow determination of both plant and non-plant effects. Four other ANOVAs (spottail shiner, yellow perch and trout-perch in trawls and spottail shiner in gill nets) fall under condition B (Table A11) and plant effects should be readily discernible. Only one ANOVA (rainbow smelt in trawls) will present more difficult analysis (condition D, Table A11) relying on multiple comparison tests for interpretation.

Power calculations indicated that comparison of 2 yr preoperational to 2 yr operational data could enable detection of moderate changes in fish abundance, at $\alpha = 0.01$ and power = 0.95. Least detectable true changes ranged from 1.46 to 1.78 for the five most abundant species in trawl catches. Spottail shiner data for gill net catches had similar power characteristics, with LDTC = 1.72. Seine ANOVAs performed on spottail shiner and alewife data were less powerful, with least detectable true changes of 2.60 and 2.23 respectively. Thus for the least powerful case, spottail shiner in seine hauls, a change by a factor of 2.60 [$y = 2.60x$, a 160% increase; or $y = x/2.60$, a 61.5% decrease] or greater will be detected as a significant difference. For spottail shiner in trawl ANOVA, the most powerful case with LDTC = 1.46, a change by a factor of 1.46 [$y = 1.46x$, increase of 46%; $y = x/1.46$, decrease of 31.5%] or more will be detected as a significant difference.

Table A12. Summary of results of tests on main factors YEAR and AREA/STATION and their interactions for preoperational ANOVAs (1973-1974). α = 0.01, SIG = significant, NS = non-significant.

		Main Effect		Highest Order of Significant Interaction	
Gear	Species	YEAR	AREA/STATION	YEAR	AREA/STATION
Trawl	spottail shiner	SIG	NS	3rd	3rd
	alewife	NS	NS	3rd	3rd
	rainbow smelt	SIG	SIG	3rd	3rd
	yellow perch	SIG	NS	2nd	none
	trout-perch	SIG	NS	2nd	none
Seine	spottail shiner	NS	NS	2nd	none
	alewife	NS	NS	3rd	3rd
Gill Net	spottail shiner	SIG	NS	2nd	2nd

While ANOVA incorporated major factors of temporal and spatial variability, it did not include effects of water temperature on fish catch. Water temperature is a major determinant of fish location and behavior (see SECTION B - Effects of Upwellings on Fish Distributions). It may be possible to include water temperature as a covariate in the analysis. The improved design, analysis of covariance (ANCOVA) (Snedecor 1956, Cochran and Cox 1957, Steel and Torrie 1960) may be able to separate effects of water temperature from effects of spatial-temporal location on fish abundance. Increase in accuracy of analysis provided by ANCOVA can be comparable to doubling the number of replicates of the original ANOVA design (Cochran and Cox 1957). However dependence of water temperature on levels of the MONTH factor may introduce insurmountable difficulties of interpretation (Winer 1971) and may preclude use of ANCOVA on fish abundance data.

A contributing factor in complexity of ANOVA was assignment of linear time to discrete levels of factors MONTH and YEAR. Seasonal variation of fish abundance contributed to significance of high-order interactions. In addition, serial correlation of observations across levels of MONTH may reduce power of certain F-tests (Scheffe 1960). Analysis of preoperational-operational data by control charting was suggested by Jensen (1973) to incorporate time as a linear factor. This procedure utilizes preoperational data to establish a base-line value equivalent to preoperational mean abundance, with action limits representing confidence limits about the mean. Data can be corrected for seasonal variation. Operational data are compared to action limits; values falling outside the action limits indicate a significant change in fish abundance. Application of this technique depends on establishment of proper preoperational

control. There must be sufficient data to establish seasonal variation. Power of detecting significant changes depends on number of samples at each time interval; this may require pooling of samples across stations for our data. If an increasing or decreasing trend in fish abundance is apparent in preoperational data, control charting may fail as a means of detecting operational effects.

Utilization of nonparametric analyses for detecting changes in fish abundance was restricted to cases that failed to meet assumptions of parametric methods. Lack of nonparametric analogs to multi-factor ANOVA requires that main effects must be analyzed by a series of individual nonparametric tests. Testing of interactions is not possible. In addition, nonparametric methods are incapable of expressing significant differences as differences in numbers of fish. Thus parametric methods are preferred when assumptions can be approximated and quantified differences are desired.

Application of balanced factorial ANOVA to preoperational fish abundance data indicated that this method of analysis could detect moderate changes in fish abundance when applied to operational data. Further, for the species and gear indicated in Table A12, such changes could be ascribed to Cook Plant impacts or non-plant causes. Power analyses indicated the minimum differences that ANOVAs could detect as significant. Additional analysis by ANCOVA or control charting may be able to increase power of the analysis, detecting smaller differences as significant. However all these procedures can only detect statistical significance, i.e., a difference in fish abundance that is too large to be considered merely an effect of random variation. Whether or not such statistically significant differences are biologically significant in terms of Cook Plant impacts must be determined on other grounds.

SECTION B

SPATIAL AND TEMPORAL DISTRIBUTION, GONAD CONDITION AND TEMPERATURE-CATCH RELATIONSHIPS OF ADULT AND JUVENILE FISHES

INTRODUCTION

This section discusses results of field sampling for adult and juvenile fish. Primarily, results of 1974 samplings are analyzed, but emphasis is also devoted to integrating 1974 and 1973 results. These analyses are made on the preoperational data base to establish natural variation in fish numbers. Attempts were also made to define causes for natural variation observed. Hopefully this analysis and interpretation of natural biological variation and causes will allow us to determine any possible plant operation effects on fish populations. A future comparison of operational data for 1975 and 1976 with preoperational data for 1973 and 1974 will assess the impact of the Cook Plant on fish in southeastern Lake Michigan.

Results and discussions in this section are organized into seven major segments. The first five segments discuss general aspects of the total fish population in the study area and some of the causes which influence distributions and our monthly total catches. Catches and biology of individual species are discussed and analyzed in the last two sections.

METHODS

Stations

Seven permanent sampling stations (A, B, C, D, F, G and H) were established in Lake Michigan off the Cook Plant (experimental area) and off Warren Dunes State Park (reference area) for sampling adult and juvenile fish (Fig. B1). Routine samples taken at these stations are referred to in this report as the standard series. At the Cook Plant there were two beach seining stations, one north (A) and one south (B) of the plant, and two stations (C,D) at 6-m (20 ft) and 9-m (30 ft) depths where trawl and gill net samples were taken. At Warren Dunes there were two stations (G,H) at 6-m and 9-m depths for trawl and gill net samples and one beach seining station (F). Stations at 6 m (C,G) and 9 m (D,H) were established to approximately correspond to depth location, based on the 1973 lake level, of the Cook Plant's two discharge and three intake structures. Based on an average lake level of 176 m (579 ft) above sea level, the discharge structures are located in approximately 5.5 m (18 ft) of water (366 m from shore) and the intake structures in 7.3 m (24 ft) of water (686 m from shore)(U.S. Atomic Energy Commission 1973).

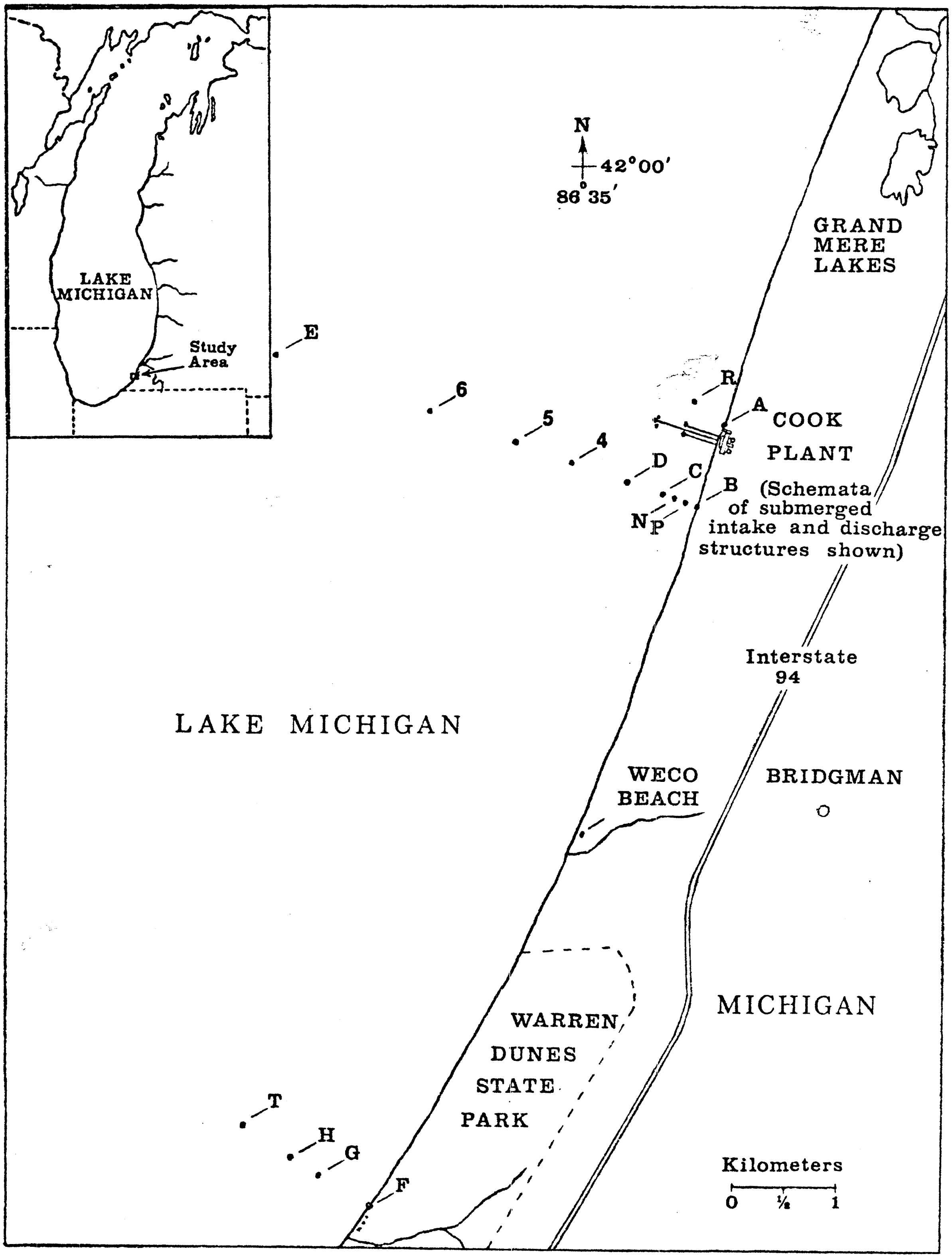


Fig. B1. Location of sampling stations at the Cook Plant and Warren Dunes study areas in southeastern Lake Michigan, 1974.

During summer and fall of 1974, Lake Township of Berrien County installed an offshore water intake near the south end of the Cook Plant property. As a result of this lake bottom disruption and the intake pipe, we had to trawl approximately 0.15 km further south of the 1973 location for Cook stations C and D. Because the trawl theoretically fishes over approximately a 0.8-km distance in 10 min, this slight extension in station location was not felt to be a significant change. In 1975 and to date trawling has continued at this extended location. No change in location of gill net sets at C and D occurred.

Although the standard series had priority, occasionally there was time to take supplementary trawl or gill net samples at standard stations or at other stations (E, 6, 5, 4, and T) (Fig. B1). Depths at these stations were E-21 m, 6-18 m, 5-15 m, 4 and T-12 m. All methods used at supplementary stations were identical to those used at standard series stations, except the setting of gill nets perpendicular to shore at beach station A in 1.5-3.0 m of water. Fish larvae samples were taken at stations R-6 m, P-1.5 m and N-3 m (Fig. B1).

Substrate at seining stations A, B and F during 1974 was sand with some gravel, which is typical of beaches in southeastern Lake Michigan. Two distinct sand bars parallel to shore were present during most sampling months. The first bar from shore was usually at the 0.5-m depth and the second at 1.5 m. Seining occurred between the first and second bars or between shore and the second bar during months when no first bar was present. Station B differed from the other two seining stations in occasionally lacking well-developed sand bars and in having some large rocks, pieces of scrap iron and concrete reinforcing steel bars (left behind when the safe harbor was removed in 1974). Fish catches at station B reflected this habitat difference.

Substrate at all deeper stations (C, D, G, H) was sandy with coarser sands at Warren Dunes (see Seibel et al. 1974 for a detailed discussion of substrates in the area). Occasionally (2-3 hauls/year) large (2-4 kg) chunks of peat were trawled at 6 m (station C) at the Cook Plant. Apparently there is an old beach zone, from when the lake level was considerably lower, that is partially exposed at station C. This area makes the substrate somewhat unique at part of this station. Slope of the bottom off the Cook Plant was steeper than off Warren Dunes, thus trawl and gill net samples from Warren Dunes were taken further offshore.

Gear

Duplicate 10-min bottom tows were taken monthly both day and night at the four deep stations (C, D, G, H), using a semi-balloon, nylon trawl having a 4.9-m (16 ft) headrope and a 5.8-m (19 ft) footrope. The body and cod end were composed respectively of 3.8-cm (1.5 in) and 3.2-cm (1.25 in) stretch mesh, while the cod end interliner was 1.3-cm (0.5 in) stretch mesh. All trawl hauls were made at an average speed of 5 km/h (3 mph) i.e., at a fixed rpm using the University of Michigan's R/V MYSIS. The trawl was

towed parallel to shore following the 6-m and 9-m depth contours; one replicate was taken from south to north and the other north to south.

Multifilament nylon experimental gill nets 160 x 1.8 m (525 x 6 ft) were set at the deeper stations (C, D, G, H) once per month for approximately 12 h during daylight and 12 h during the night. Nets were composed of 12 panels of netting as follows: 7.6-m (25 ft) sections of each of the following mesh sizes (bar measure) -- 1.3-cm (0.5 in), 1.9-cm (0.75 in) and 2.5-cm (1 in); 15.2-m (50 ft) sections of mesh sizes 3.2-7.6 cm (1.25-3.0 in) by 0.64-cm (0.25 in) intervals; and a final 15.2-m section of 10-cm (4 in) mesh. All gill nets were set parallel to shore on the bottom, except beach station A supplementary sets which were set perpendicular to shore.

Beach seining was usually conducted during periods of reduced wave height using a nylon seine 38 m x 1.8 m (125 ft x 6 ft) with a 1.8 x 1.8 x 1.8-m bag; the entire seine had 0.64-cm (0.25-in) bar mesh. Jude et al. 1975 (page 27) listed the bag as 9.1 m, but this is an error; the correct measurement is 1.8 m. The seine was first stretched perpendicular to the shoreline and then pulled parallel to shore a distance of 61 m (200 ft). Duplicate, non-overlapping samples were taken in this manner both day and night once each month at seining stations (A, B, F). The seine was pulled against the current or southerly when no current was detectable. When the current was too strong to seine against, seining was done with the current.

Missing Samples

In summary, the standard monthly sample series consisted of 16 trawl hauls, 8 gill net sets and 12 beach seine hauls. While it was hoped that standard series fishing could be performed every month of the year, this was not always possible due to equipment failure, inclement weather and ice. Following is a summary of samples missing from the standard series in 1974 (missing observations in parentheses):

1. January - all trawls (16), day gill nets (4), night gill nets at G and H (2), day seines at B (1) and F (2), all night seines (6).
2. February - all trawls (16), gill nets (8) and seines (12).
3. March - all trawls (16).
4. November - day trawls (8).
5. December - all trawls (16) and seines (12).

In RESULTS AND DISCUSSION selected station fishing data were designated as the standard series, other netting was termed supplementary, and when all fishing activities were combined this was called total fishing efforts or total samples.

Physical and Limnological Data

Each time a particular fishing gear was used at a station, weather and other physical parameters were recorded (Tables B1-3). Wind direction and

Table B1 . Date (month-day), time (EST) and some physical and limnological parameters measured during standard series trawling 1974.

Date	Starting time	Station	Temp C Surface	Temp C Fishing depth	Wind Dir. from	Wind MPH	Waves Dir. from	Waves Height (m)	Weather	Secchi disc(m)
4-17	1130	C	8.6	7.7	S	5-10	SW	.3	sunny & haze	1.2
4-17	1147	C	8.6	7.7	S	5-10	SW	.3	sunny & haze	1.2
4-17	2300	C	7.2	6.4	S	0-5	calm		clear	-
4-17	2320	C	7.2	6.4	calm		calm		clear	-
4-17	1338	D	9.2	8.0	SW	5-10	SW	.3	sunny & haze	1.5
4-17	1359	D	9.2	8.0	SW	5-10	SW	.3	sunny & haze	1.5
4-16	2144	D	7.3	6.0	S	0-5	calm		clear	-
4-16	2210	D	7.3	6.0	S	0-5	calm		clear	-
4-16	1415	G	8.6	7.4	NW	0-5	NW	.3	clear	1.0
4-16	1442	G	8.8	7.4	NW	0-5	NW	.3	clear	1.0
4-16	1943	G	8.0	7.6	calm		calm		clear	-
4-16	2000	G	8.0	7.6	calm		calm		clear	-
4-16	1540	H	8.8	6.5	NW	0-5	NW	.3	clear	1.0
4-16	1603	H	8.8	6.5	NW	0-5	NW	.3	clear	1.0
4-16	2052	H	7.9	6.4	W	0-5	calm		clear	-
4-16	2110	H	7.9	6.4	calm		calm		clear	-
5-13	1553	C	9.5	9.1	SE	5-10	SE	.2	partly cloudy	1.6
5-13	1615	C	9.5	9.1	SE	5-10	SE	.2	partly cloudy	1.6
5-13	2350	C	9.2	8.8	SE	15-20	SE	.3-.6	partly cloudy	-
5-14	0010	C	9.2	8.8	SE	15-20	SE	.3-.6	partly cloudy	-
5-13	1430	D	9.2	9.0	SE	5-10	SE	.3	overcast	1.7
5-13	1450	D	9.2	9.0	SE	5-10	SE	.3	overcast	1.7
5-13	2233	D	9.3	8.4	SE	15-20	SE	.3-.6	partly cloudy	-
5-13	2253	D	9.3	8.4	SE	15-20	SE	.3-.6	partly cloudy	-
5-14	1157	G	10.5	10.1	SW	5-10	SW	.6	partly cloudy	2.0
5-14	1213	G	10.5	10.1	SW	5-10	SW	.6	partly cloudy	2.0
5-13	2103	G	9.8	9.3	E	5-10	SE	.3	partly cloudy	-
5-13	2121	G	9.8	9.3	E	5-10	SE	.3	partly cloudy	-
5-14	1045	H	10.0	9.9	SW	10-15	S	.6	partly cloudy	2.5
5-14	1102	H	10.0	9.9	SW	10-15	S	.6	partly cloudy	2.5
5-13	1940	H	9.5	8.9	E	5-10	SE	.3	partly cloudy	-
5-13	2004	H	9.5	8.9	E	5-10	SE	.3	partly cloudy	-
6-12	1443	C	17.6	16.4	SW	0-5	W	.2	sunny & haze	4.0
6-12	1500	C	17.6	16.4	SW	0-5	W	.2	sunny & haze	4.0
6-12	0047	C	14.2	14.2	SW	10-15	SW	.3	clear	-
6-12	0103	C	14.2	14.2	SW	10-15	SW	.3	clear	-
6-12	1323	D	17.0	15.0	SW	0-5	W	.2	clear	4.0
6-12	1340	D	17.0	15.0	SW	0-5	W	.2	clear	4.0
6-11	2329	D	14.1	14.2	SW	5-10	SW	.3	overcast	-
6-11	2347	D	14.1	14.2	SW	5-10	SW	.3	overcast	-
6-11	1642	G	15.3	15.0	calm		W	.3	partly cloudy	2.7
6-11	1659	G	15.3	15.0	calm		W	.3	partly cloudy	2.7
6-11	2024	G	14.0	14.5	W	5-10	W	.2	partly cloudy	-
6-11	2045	G	14.0	14.5	W	5-10	W	.2	partly cloudy	-
6-11	1527	H	14.5	15.0	SW	10-15	SW	.3-.6	overcast & rain	3.0
6-11	1545	H	14.5	15.0	W	10-15	W	.6	overcast & rain	3.0
6-11	2131	H	13.8	14.3	SW	0-5	W	.2	partly cloudy	-
6-11	2152	H	13.8	14.3	SW	0-5	W	.2	partly cloudy	-
7-09	1359	C	25.0	19.9	calm		calm		sunny & haze	1.5
7-09	1418	C	25.0	19.9	calm		calm		sunny & haze	1.5
7-09	0045	C	21.8	15.0	S	15-20	N	.3	overcast & haze	-
7-09	0102	C	21.8	15.0	S	15-20	N	.3	overcast & haze	-
7-09	1154	D	23.6	11.3	S	0-5	calm		sunny & haze	2.0
7-09	1212	D	23.6	11.3	S	0-5	calm		sunny & haze	2.0
7-08	2325	D	21.2	10.2	S	0-5	calm		overcast & haze	-
7-08	2344	D	21.2	10.2	S	0-5	calm		overcast & haze	-

Table B1. continued.

Date	Starting time	Station	Temp C Surface	Temp C Fishing depth	Wind Dir. from	Wind MPH	Waves Dir. from	Waves Height (m)	Weather	Secchi disc (m)
7-08	1546	G	24.4	17.6	S	0-5	calm		sunny & haze	2.9
7-08	1603	G	24.4	17.6	S	0-5	calm		sunny & haze	2.9
7-08	2150	G	21.5	11.3	SE	5-10	calm		overcast & haze	-
7-08	2210	G	21.5	11.3	SE	5-10	calm		overcast & haze	-
7-08	1422	H	23.7	14.8	calm		calm		sunny & haze	2.9
7-08	1443	H	23.7	14.8	calm		calm		sunny & haze	2.9
7-08	2033	H	24.0	10.5	SW	0-5	N	.2	overcast & haze	-
7-08	2049	H	24.0	10.5	SW	0-5	N	.2	overcast & haze	-
8-20	1350	C	24.0	22.5	calm		calm		sunny & haze	5.0
8-20	1410	C	24.0	22.5	calm		calm		sunny & haze	5.0
8-20	0018	C	20.5	19.2	NE	5-10	calm		clear	-
8-20	0038	C	20.5	19.5	NE	5-10	calm		clear	-
8-20	1230	D	23.4	20.0	calm		calm		sunny & haze	5.0
8-20	1250	D	23.4	20.0	calm		calm		sunny & haze	5.0
8-19	2256	D	21.8	16.4	SE	5-10	calm		-	-
8-19	2314	D	21.8	16.4	SE	5-10	calm		-	-
8-19	1644	G	22.2	17.9	calm		calm		sunny & haze	4.9
8-19	1700	G	22.2	17.9	calm		calm		sunny & haze	4.9
8-19	2130	G	21.5	18.1	NE	5-10	calm		partly cloudy	-
8-19	2145	G	21.5	18.1	NE	5-10	calm		partly cloudy	-
8-19	1524	H	21.9	15.0	calm		calm		sunny & haze	4.5
8-19	1543	H	21.9	15.0	calm		calm		sunny & haze	4.5
8-19	2009	H	22.4	12.7	NE	0-5	calm		partly cloudy	-
8-19	2025	H	22.4	12.7	calm		calm		partly cloudy	-
9-10	1338	C	19.7	19.0	calm		calm		clear	3.7
9-10	1355	C	19.7	19.0	calm		calm		clear	3.7
9-09	2326	C	19.0	17.5	SE	5-10	calm		partly cloudy	-
9-09	2345	C	19.0	17.5	SE	5-10	calm		partly cloudy	-
9-10	1146	D	19.5	18.0	calm		calm		clear	4.0
9-10	1205	D	19.5	18.0	calm		calm		clear	4.0
9-09	2211	D	19.2	17.2	SE	5-10	SW	<.2	partly cloudy	-
9-09	2229	D	19.2	17.2	SE	5-10	SW	<.2	partly cloudy	-
9-09	1636	G	19.2	17.6	calm		calm		partly cloudy	3.5
9-09	1655	G	19.2	17.6	calm		calm		partly cloudy	3.5
9-09	2045	G	19.5	17.5	SW	5-10	calm		partly cloudy	-
9-09	2103	G	19.5	17.5	SW	5-10	calm		partly cloudy	-
9-09	1505	H	19.5	17.5	calm		calm		clear	3.5
9-09	1537	H	19.5	17.5	calm		calm		clear	3.5
9-09	1929	H	19.0	16.8	calm		calm		partly cloudy	-
9-09	1946	H	19.0	16.8	calm		calm		partly cloudy	-
10-08	1430	C	13.5	13.5	SW	10-15	SW	.6-.9	partly cloudy	2.0
10-08	1447	C	13.5	13.5	SW	10-15	SW	.6-.9	partly cloudy	2.0
10-08	1957	C	14.0	13.5	S	10-15	SW	.3-.6	partly cloudy	-
10-08	2019	C	14.0	13.5	S	10-15	SW	.3-.6	partly cloudy	-
10-08	1313	D	14.0	13.5	SW	10-15	SW	.6-.9	partly cloudy	2.0
10-08	1335	D	14.0	13.5	SW	10-15	SW	.6-.9	partly cloudy	2.0
10-08	1838	D	14.0	13.5	S	5-10	SW	.6	partly cloudy	-
10-08	1900	D	14.0	13.5	S	5-10	SW	.6	partly cloudy	-
10-08	1126	G	13.5	13.0	SW	10-15	SW	.6	partly cloudy	2.0
10-08	1145	G	13.5	13.0	SW	10-15	SW	.6	partly cloudy	2.0
10-07	2030	G	13.0	13.0	SE	5-10	NW	.9-1.2	partly cloudy	-
10-07	2050	G	13.0	13.0	SE	5-10	NW	.9-1.2	partly cloudy	-
10-08	1010	H	13.0	13.0	SW	5-10	SW	.6-.9	partly cloudy	2.0
10-08	1030	H	13.0	13.0	SW	5-10	SW	.6-.9	partly cloudy	2.0
10-07	1913	H	13.0	13.5	NE	5-10	NW	.9-1.2	partly cloudy	-
10-07	1934	H	13.0	13.5	NE	0-5	NW	.9-1.2	partly cloudy	-
11-10	2312	C	9.9	10.1	SE	10-15	S	.2	overcast & rain	-
11-10	2334	C	9.9	10.1	SE	10-15	S	.2	overcast & rain	-
11-10	2154	D	10.5	10.1	SE	0-5	S	.2	overcast & rain	-
11-10	2210	D	10.5	10.1	SE	0-5	S	.2	overcast & rain	-
11-10	2006	G	9.9	10.1	SE	5-10	calm		overcast & rain	-
11-10	2024	G	9.9	10.1	SE	5-10	calm		overcast & rain	-
11-10	1845	H	10.5	10.5	SE	5-10	calm		overcast & rain	-
11-10	1903	H	10.5	10.5	SE	5-10	calm		overcast & rain	-

Table B2. Date (month-day), time (EST) and some physical and limnological parameters measured during standard series and supplementary gillnetting, 1974.

Starting date	Time: Start	Time: Finish	Station	Temp C: Surface	Temp C: Fishing depth	Wind: Dir. from	Wind: MPH	Waves: Dir. from	Waves: Height (m)	Weather	Secchi disc (m)
*1-28	2200	1200	A	1.5	1.5	W	0-5	W	.3-.5	partly cloudy	1.0
*1-28	2230	1230	A	1.5	1.5	W	0-5	W	.3-.5	partly cloudy	-
1-03	1645	1030	C	0.2	0.2	W	15-20	WNW	1.4	clear	.9
1-03	1700	1050	D	0.5	0.5	W	20-25	WNW	1.4	clear	.9
*1-03	1750	1200	E	0.2	0.5	W	20-25	WNW	1.5	clear	.8
*1-03	1850	1300	E	0.9	1.0	WNW	20-25	WNW	1.5	clear	-
*3-06	1120	1505	A	4.5	4.2	S	0-10	SW	.3-.6	overcast	-
*3-15	1030	1705	A	3.5	3.5	SE	5-10	SE	calm	cloudy, rain	0.7
3-15	0815	1745	C	3.5	3.5	SE	10	calm		cloudy	0.7
3-06	2130	0925	C	4.0	3.0	SSE	0-5	S	.2	cloudy	-
3-15	0830	1725	D	3.5	3.5	SE	5-10	calm		cloudy, rain	0.7
3-06	2230	0915	D	4.0	3.0	SSE	0-5	S	.2	cloudy	-
*3-15	0930	1740	E	2.5	†2.5	SE	5	calm		cloudy	-
3-15	0750	1630	G	3.3	3.2	SE	10	calm		cloudy, fog	-
3-14	1950	0645	G	2.9	3.0	SE	0-5	SE	.2	cloudy	-
*3-06	1940	0820	G	2.7	3.1	S	0-5	S	.2	fog	-
*3-06	1955	0835	G	2.7	3.1	S	0-5	S	.2	clear	-
3-15	0740	1640	H	2.9	3.3	SE	10	calm		cloudy, fog	0.7
3-14	2100	0650	H	3.4	3.4	-	-	-	-	cloudy	-
*4-10	0900	1300	A	5.9	5.4	SE	10-15	SE	.3	clear	-
*4-18	0600	1600	A	8.8	8.1	SW	5-10	SW	.3	partly cloudy & rain	1.5
*4-19	1400	1845	A	9.8	7.9	NW	10-15	NE	.5	clear	-
4-17	1025	1930	C	7.3	7.1	S	5-10	S	.3	clear	1.0
4-16	2130	1015	C	7.3	7.1	S	5-10	S	.3	clear	1.0
4-16	0710	2050	D	7.2	7.1	N	0-5	NW	.3	clear	1.3
4-16	2145	1035	D	7.3	7.1	S	0-5	S	.3	clear	1.0
*4-19	1520	2000	E	7.3	-	NW	10-15	NE	.5	clear	-
4-17	0905	2000	G	7.3	7.2	S	5-10	S	.5	clear	1.5
4-16	2000	0850	G	7.7	7.0	S	5-10	S	.5	clear	1.5
4-16	0755	1930	H	7.0	7.0	N	0-5	NW	.3	clear	1.3
4-16	2015	0935	H	7.1	7.1	S	5-10	S	.5-.6	clear	1.5
*4-16	0725	2100	4	6.1	6.7	N	0-5	NW	.3	clear	1.5
*4-16	0805	1920	4	6.5	6.7	N	0-5	NW	.3	clear	1.5
*5-13	0730	1900	A	10.2	10.0	NW	0-5	NW	.9	rain & overcast	-
*5-15	2130	0655	A	10.7	10.7	calm	0-5	calm		partly cloudy	2.6
5-13	0640	1910	C	-	8.9	NW	0-5	NW	.9	rain & overcast	-
5-15	2110	0632	C	10.6	10.6	calm		calm		partly cloudy	2.5
5-13	0620	1920	D	9.0	8.5	NW	0-5	NW	.9	rain & overcast	-
5-15	2120	0622	D	10.5	10.5	calm		calm		-	2.5
*5-20	2035	0725	E	10.0	-	SE	0-5	calm		clear	4.5
5-13	0705	1935	G	-	8.9	NW	0-5	NW	.9	rain & overcast	-
5-15	2200	0745	G	11.0	10.6	calm		calm		partly cloudy	-
5-13	0655	1950	H	9.0	8.4	NW	0-5	NW	.9	rain & overcast	-
5-15	2210	0730	H	11.0	9.5	calm	0-5	calm		partly cloudy	-
*6-14	1040	1600	A	17.8	17.5	calm		calm	.1	clear	3.8
*6-12	2145	0545	A	16.0	15.5	SW	0-5	SW	.2	partly cloudy	-
6-13	0610	1855	C	15.6	15.6	SW	5-10	SW	.3	clear	3.5
6-11	2230	0500	C	15.0	14.6	SW	10-15	SW	.3	clear	-
*6-01	1950	0925	C	14.9	13.1	N	0-5	NW	.3	haze	2.1
6-13	0615	1909	D	15.5	15.0	SW	5-10	SW	.3	clear	4.0
6-11	2245	0508	D	14.6	14.8	SW	5-10	SW	.3	rain & overcast	-
*6-01	2000	0915	D	15.3	11.6	N	5-10	NW	.3	haze	2.6
6-13	0650	1957	G	15.0	15.2	SW	5-10	SW	.3	clear	4.0
6-11	2130	0540	G	15.0	14.5	W	5-10	W	.2	partly cloudy	-
6-13	0700	1944	H	15.2	15.2	SW	0-5	S	.2-.3	clear	4.0

Table B2. continued.

Starting date	Time Start	Time Finish	Station	Temp C Surface	Temp C Fishing depth	Wind Dir. from	Wind MPH	Waves Dir. from	Waves Height (m)	Weather	Secchi disc(m)
6-11	2145	0550	H	14.9	14.9	var.	0-5	W	.2	partly cloudy	-
*7-10	0730	1850	A	22.6	19.7	NW	5-10	NW	.3-.5	overcast	2.8
*7-11	0010	0830	A	22.6	19.7	NE	0-5	N	.2	overcast	-
7-10	0710	1905	C	22.2	16.6	NW	5-10	NW	.3-.5	overcast	-
7-08	2226	0541	C	22.0	16.0	calm		calm		clear	-
7-10	0640	1915	D	22.0	12.7	NW	5-10	NW	.3-.5	overcast	3.0
7-08	2236	0655	D	21.9	12.8	calm		calm		clear	-
*7-10	1940	0800	E	-	9.0	NE	5-10	NW	.2	partly cloudy	-
7-10	0945	2000	G	22.0	19.0	N	5-10	NW	.3-.5	overcast	2.5
7-08	2328	0455	G	20.4	15.9	SE	0-5	calm		clear	-
7-10	0930	2010	H	22.3	16.5	N	5-10	NW	.3-.5	overcast	3.0
7-08	2318	0506	H	22.0	12.5	calm		calm		haze	-
*8-22	0820	1400	A	23.6	23.2	SE	0-5	SW	.2	clear	-
*8-20	2145	0620	A	21.5	20.0	SE	0-5	calm		clear	-
8-21	0640	1745	C	23.4	22.2	calm		calm		clear	5.5
8-19	2100	0630	C	20.5	19.5	SW	0-5	calm		clear	-
8-21	0650	1800	D	23.3	19.6	calm		calm		-	6.0
8-19	2110	0615	D	20.5	16.4	SW	0-5	calm		clear	-
*8-21	1100	0600	E	-	6.5	SE	5-10	SE	.2-.3	clear	-
8-21	0710	1800	G	21.1	20.5	SE	5-10	SE	.2	haze	5.0
8-19	2200	0526	G	21.5	18.1	SW	0-5	SW	.2	clear	-
8-21	0650	1750	H	21.0	19.1	SE	0-5	SE	.2	haze	5.4
8-19	2210	0536	H	22.4	12.7	SW	0-5	SW	.2	clear	-
*9-11	1120	1730	A	19.2	19.2	SW	10-15	SW	.6	partly cloudy & haze	-
*9-09	2150	0730	A	19.0	18.4	SE	0-5	calm		partly cloudy	-
9-10	0840	1900	C	18.5	18.5	S	0-5	SW	.1-.2	overcast & haze	4.0
9-10	2130	0530	C	19.6	18.3	SE	0-5	calm		partly cloudy	-
9-10	0850	1845	D	18.4	18.2	S	0-5	SW	.2	overcast & haze	4.1
9-09	2142	0545	D	19.0	17.6	SE	0-5	calm		partly cloudy	-
*9-10	1450	1130	E	18.4	7.5	SE	5-10	calm		haze	-
9-10	0715	1920	G	18.5	18.0	S	5-10	SW	.1	overcast & haze	4.0
9-09	2240	0605	G	18.5	18.0	SE	0-5	calm		partly cloudy	-
9-10	0645	1910	H	18.5	18.0	S	5-10	SW	.1	overcast & haze	4.2
9-09	2255	0600	H	18.5	17.7	SE	0-5	calm		partly cloudy	-
*10-10	0940	1615	A	13.6	13.6	W	5-10	W	.9	clear	1.2
*10-08	2130	0715	A	12.8	12.8	SW	10-15	SW	.3-.6	overcast	-
10-10	0915	1630	C	13.0	13.3	W	10-15	W	.9	clear	1.2
10-08	2000	0900	C	14.0	13.5	SW	10-15	SW	.3-.6	overcast	-
10-10	0930	1640	D	13.6	13.5	W	10-15	W	.9	clear	1.5
10-08	2008	0800	D	14.0	13.5	SW	10-15	SW	.3-.6	overcast	-
*10-23	1532	0944	E	12.9	-	E	0-5	S	0-.3	overcast & fog	4.0
10-09	0920	1910	G	14.0	13.0	NW	10-15	W	1.2	partly cloudy	2.0
10-08	2100	0700	G	13.1	13.0	SW	10-15	SW	.3-.6	overcast	2.0
10-09	0830	1900	H	14.5	13.8	NW	10-15	W	1.2	partly cloudy	2.0
10-08	2045	0630	H	14.0	13.8	SW	10-15	SW	.3-.6	overcast	2.0
*11-26	2200	0930	A	4.7	4.6	SE	10-15	calm		partly cloudy	-
11-29	0830	1630	C	5.2	4.9	NW	10-15	N	.9-1.2	overcast	.6
11-10	1815	0950	C	9.9	10.1	SE	10-15	S	.2	rain & overcast	-
11-29	0842	1640	D	5.4	5.1	NW	10-15	N	.9-1.2	overcast	.6
11-10	1800	0930	D	10.5	10.1	SE	0-5	S	.2	rain & overcast	-
*11-29	0905	1700	E	6.6	6.2	NW	10-15	N	.9-1.2	overcast	.6
11-29	0750	1547	G	5.4	5.0	NW	10-15	N	.9-1.2	overcast	.6
11-10	2118	0845	G	9.9	10.1	SE	5-10	calm		rain & overcast	-
11-29	0740	1532	H	6.5	5.4	NW	10-15	N	.9-1.2	overcast	.6
11-10	2136	0830	H	10.5	10.5	SE	5-10	calm		rain & overcast	-
*12-20	0900	1640	A	1.8	1.9	SE	10-15	SW	.3-.6	overcast & snow	.6
12-20	0825	1615	C	2.2	1.9	SE	10-15	SW	.3-.6	overcast & snow	.6
12-24	1640	0840	C	3.2	2.5	SE	0-5	calm		overcast	.6
12-20	0810	1630	D	2.2	2.0	SE	10-15	SW	.3-.6	overcast & snow	-
12-24	1650	0855	D	1.9	2.3	SE	0-5	calm		overcast	.6
*12-20	0850	1700	E	4.0	4.0	SE	10-15	SW	.3-.6	overcast & snow	1.5
*12-24	1535	1100	E	3.9	3.9	SE	0-5	SE	.3	overcast	3.7
12-20	0745	1530	G	2.2	1.9	SE	10-15	SW	.3-.6	overcast & snow	-
12-24	1740	0955	G	2.5	2.2	SE	0-5	calm		overcast	-
12-20	0732	1515	H	2.8	2.1	SE	10-15	SW	.3-.6	overcast & snow	.6
12-24	1730	0945	H	2.1	2.2	SE	0-5	calm		overcast	.6

*Supplementary set, remaining sets are standard series.
†Temperature at 15.2m.

Table B3. Date (month-day), time (EST) and some physical and limnological parameters measured during standard series and supplementary seining, 1974.

Date	Starting time	Station	Temp C Surface	Temp C Fishing depth	Wind Dir. from	Wind MPH	Waves Dir. from	Waves Height (m)	Weather	Secchi disc (m)
1-29	1315	A	0.4	0.4	S	5-10	SW	.6	overcast	1.0
1-29	1330	A	0.4	0.4	S	5-10	SW	.6	overcast	1.0
1-29	1425	B	0.4	0.4	SE	10-15	S	.6-.9	overcast	1.0
3-15	1030	A	4.0	4.1	S	5	S	0-.2	overcast & rain	0.5
3-15	1040	A	4.0	4.1	S	5	S	0-.2	overcast	0.5
3-06	2220	A	6.2	6.2	W	0-5	SW	.2	cloudy	-
3-06	2245	A	6.2	6.2	W	0-5	SW	.2	cloudy	-
3-15	0900	B	3.8	3.8	S	5		calm	cloudy & rain	-
3-15	0920	B	3.8	3.8	S	5		calm	cloudy	-
3-06	2050	B	6.2	6.2	W	0-5	SW	.2	clear	-
3-06	2100	B	6.2	6.2	W	0-5	SW	.2	clear	-
3-15	0810	F	3.5	3.7	SE	5	SE	0-.2	cloudy	-
3-15	0825	F	3.5	3.7	SE	5	SE	0-.2	cloudy	-
3-14	2015	F	4.2	5.0	SE	5	S	0-.2	cloudy	-
3-14	2030	F	4.2	5.0	SE	5	S	0-.2	cloudy	-
4-18	1525	A	12.0	12.0	NW	5-10	NW	.3-.6	sunny & haze	0.9
4-18	1535	A	12.0	12.0	NW	5-10	NW	.3-.6	sunny & haze	0.9
4-20	0120	A	7.4	7.3	E	0-5	NE	0	clear	-
4-20	0135	A	7.4	7.3	E	0-5	NE	0	clear	-
4-18	1410	B	11.5	11.3	W	5-10	NW	.3	sunny & clear	0.7
4-18	1420	B	11.5	11.3	W	5-10	NW	.2	sunny & haze	0.7
4-20	0035	B	7.1	7.1	NE	0-5		calm	clear	-
4-20	0050	B	7.1	7.1	NE	0-5		calm	clear	-
4-18	1256	F	12.0	11.3	W	5-10	N	.3	sunny & haze	0.8
4-18	1315	F	12.0	11.3	W	5-10	N	.3	sunny & haze	0.8
4-19	2305	F	7.8	7.8	NE	0-5	NW	calm-swells	clear	-
4-19	2310	F	7.8	7.8	NE	0-5	NW	calm-swells	clear	-
5-17	1425	A	12.7	12.5	NE	0-5	N	.3	overcast & haze	0.7
5-17	1435	A	12.7	12.5	NE	0-5	N	.3	overcast & haze	0.7
5-16	0105	A	11.1	11.1	N	0-5	N	calm-.2	clear	-
5-16	0125	A	11.1	11.1	N	0-5		calm	clear	-
5-17	1340	B	12.1	12.1	N	5-10	N	.6	overcast & haze	1.0
5-17	1350	B	12.1	12.1	N	5-10	N	.6	overcast & haze	1.0
5-16	0025	B	12.5	12.4	N	0-5		calm	clear	-
5-15	2400	B	12.0	11.9	N	0-5		calm	clear	-
5-17	1225	F	12.7	12.5	N	5-10	NW	.6	overcast & haze	0.3
5-17	1240	F	12.7	12.5	N	5-10	NW	.6	overcast & haze	0.3
5-15	2225	F	11.9	11.9	var.	0-5		calm	clear	-
5-15	2245	F	11.9	11.9	var.	0-5		calm	clear	-
6-05	1415	A	17.7	18.0	S	5-10	SW	.3	overcast & rain	1.0
6-05	1430	A	17.7	18.0	S	5-10	SW	.3	overcast & rain	1.0
6-04	0035	A	18.5	18.5	S	0-5		calm	clear	-
6-04	0055	A	18.5	18.5	S	0-5		calm	clear	-
6-05	1300	B	18.5	18.2	S	5-10	SW	.2-.3	overcast & rain	1.0
6-05	1316	B	18.5	18.2	S	5-10	SW	.2-.3	overcast & rain	1.0
6-04	2305	B	18.0	18.0	E	0-5		calm	clear	-
6-04	2340	B	18.0	18.0	S	0-5		calm	clear	-
6-05	1152	F	17.5	18.0	SE	5-10	SW	.2	overcast	1.0
6-05	1205	F	17.5	18.0	SE	5-10	SW	.2	overcast	1.0
6-04	2125	F	17.5	17.5	E	0-5		calm	clear	-
6-04	2135	F	17.5	17.5	E	5-10		calm	clear	-
7-17	1540	A	22.5	22.0	SW	0-5		calm	sunny & haze	>1.5
7-17	1550	A	22.5	22.0	SW	0-5		calm	sunny & haze	>1.5
7-17	2340	A	21.0	21.0	SW	5-10	S	.3	clear	-
7-17	2350	A	21.0	21.0	SW	5-10	S	.3	clear	-

Table B3. continued.

Date	Starting time	Station	Temp C Surface	Temp C Fishing depth	Wind Dir. from	Wind MPH	Waves Dir. from	Waves Height (m)	Weather	Secchi disc (m)
7-17	1445	B	22.0	22.0	SE	0-5	calm		sunny & haze	>1.5
7-17	1455	B	22.0	22.0	SE	0-5	calm		sunny & haze	>1.5
7-17	2250	B	21.5	21.5	SE	5-10	S	.3	clear	-
7-17	2310	B	21.5	21.5	SE	5-10	S	.3	partly cloudy	-
7-17	1305	F	20.2	20.2	SE	0-5	SE	.2	clear	>1.5
7-17	1315	F	20.2	20.2	SE	0-5	SE	.2	clear	>1.5
7-17	2145	F	21.0	20.5	SE	5-10	S	.3	clear	-
7-17	2155	F	21.0	20.5	SE	5-10	S	.3	clear	-
8-14	1015	A	13.1	12.9	SE	0-5	W	.2	clear	>1.0
8-14	1035	A	13.1	12.9	SE	0-5	W	.2	clear	>1.0
8-14	2225	A	17.7	17.7	NE	0-5	NW	.3	clear	-
8-14	2235	A	17.7	17.7	NE	0-5	NW	.3	clear	-
8-14	0910	B	12.9	11.7	SE	0-5	W	.1-.2	clear	>1.0
8-14	0920	B	12.9	11.7	SE	0-5	W	.1-.2	clear	>1.0
8-14	2200	B	17.0	16.8	NE	0-5	N	.3	clear	-
8-14	2215	B	17.0	16.8	NE	0-5	NW	.3	clear	-
8-14	1125	F	12.0	12.0	S	0-5	W	.1-.2	clear	>1.0
8-14	1145	F	12.0	12.0	S	0-5	NE	.1-.2	clear	>1.0
8-15	0001	F	14.5	14.1	NE	0-5	NW	.3	clear	-
8-15	0010	F	14.5	14.1	NE	0-5	NW	.3	clear	-
9-11	1415	A	22.5	22.5	S	0-5	W	.3	pt. cloudy & haze	>1.0
9-11	1424	A	22.5	22.5	S	0-5	W	.3	pt. cloudy & haze	>1.0
9-11	2331	A	20.8	20.8	SW	0-5	SW	.2	overcast & rain	-
9-11	2337	A	20.8	20.8	SW	0-5	SW	.2	overcast & rain	-
9-11	1255	B	22.5	22.3	S	0-5	W	.3	sunny & haze	>2.0
9-11	1307	B	22.5	22.3	S	0-5	W	.3	sunny & haze	>2.0
9-11	2253	B	22.3	22.3	SW	0-5	SW	.2	overcast & rain	-
9-11	2302	B	22.3	22.3	SW	0-5	SW	.2	overcast & rain	-
9-11	1457	F	21.0	20.8	S	0-5	calm		pt. cloudy & rain	>1.0
9-11	1505	F	21.0	20.8	S	25+	W	.5	rain, hail, overcast	-
9-11	2200	F	20.8	20.8	SW	0-5	SW	.2	overcast & rain	-
9-11	2210	F	20.8	20.8	SW	0-5	SW	.2	overcast & rain	-
10-09	1507	A	14.5	14.7	W	0-5	W	.5-.6	clear	1.0
10-09	1517	A	14.5	14.7	W	0-5	W	.5-.6	clear	1.0
10-08	2120	A	13.3	13.3	S	5-10	SW	.5-.6	overcast	-
10-08	2130	A	13.3	13.3	S	5-10	SW	.5-.6	overcast	-
10-09	1415	B	14.8	14.6	SW	5-10	W	.5-.6	clear	1.0
10-09	1425	B	14.8	14.6	SW	5-10	W	.6	clear	1.0
10-08	2040	B	12.8	12.8	S	5-10	SW	.5-.6	overcast	-
10-08	2050	B	12.8	12.8	S	5-10	SW	.5-.6	overcast	-
10-09	1325	F	14.0	14.0	SW	5-10	SW	.9	sunny & haze	0.6
10-09	1335	F	14.0	14.0	SW	5-10	SW	.9	sunny & haze	0.6
10-08	2220	F	12.8	13.7	S	5-10	SW	.5-.6	overcast	-
10-08	2230	F	12.8	13.7	S	5-10	SW	.5-.6	overcast	-
11-26	1610	A	5.5	6.0	SE	10-15	calm		overcast	.5
11-26	1625	A	5.5	6.0	SE	10-15	calm		overcast	.5
11-26	2000	A	4.7	4.6	SE	10-15	calm		partly cloudy	-
11-26	2010	A	4.7	4.6	SE	10-15	calm		partly cloudy	-
11-26	1635	B	5.2	5.2	S	5-10	calm		overcast	0.6
11-26	1645	B	5.2	5.2	S	5-10	calm		overcast	0.6
11-26	2025	B	5.5	5.5	SE	10-15	calm		partly cloudy	-
11-26	2035	B	5.0	5.0	SE	10-15	calm		partly cloudy	-
11-26	1640	F	5.0	5.1	SE	10-15	calm		partly cloudy	0.2
11-26	1650	F	5.0	5.1	SE	10-15	calm		partly cloudy	0.2
11-26	1800	F	5.0	5.1	SE	10-15	calm		partly cloudy	-
11-26	1810	F	5.0	5.1	SE	10-15	calm		partly cloudy	-

speed were obtained using an anemometer and weather vane when aboard the R/V MYSIS and estimated at other times. Wave direction and height were estimated visually. Water temperatures for trawl, gill net and seine samples were taken at the surface and fishing depth (bottom) using a battery operated telethermometer (Hydrolab Model T-4 or Yellow Springs instrument Model 44TD). A pocket thermometer was sometimes used during beach seining. Secchi disc readings were taken during daytime each time a fishing gear was used.

Laboratory Analysis of Fish

Fish from seines, gill nets and trawls were processed fresh when time permitted, otherwise they were put in plastic bags and frozen at the Cook Plant as soon as possible (usually within 2 h) and stored in freezers. Trawl catches were frozen immediately on board the R/V MYSIS. At the laboratory, bags of fish were thawed as needed, separated by species, then grouped according to size classes. When large numbers of a particular size class were present, a subsample was randomly selected and a mass weight of the remaining group taken. Total length (TL) (to nearest mm, fin pinched), weight (to nearest 0.1 g using a P1000 Mettler balance), sex, gonad condition, presence of food in the stomach, fin clips, lamprey scars, evidence of disease and macro-parasites were recorded for all fish except those mass weighed. Large fish and fish in mass weights (>1000 g) were weighed with a hanging scale spring balance (K023G Chatillon) to the nearest 25 g.

Gonad condition was described according to five stages of development: 1) underdeveloped, 2) moderately developed - for females, eggs discernible but not fully ripe, 3) ripe, 4) ripe-running - sex products exiting with application of moderate pressure and 5) spent. Other categories included: 6) fish decomposed or mutilated (traveling screen catches at times) so that sex was impossible to determine, 7) unable to ascertain sex on an adult fish and 8) immature.

All fish were identified to species using Hubbs and Lagler (1964), Trautman (1957), Eddy (1957) and Scott and Crossman (1973), with the exception of the genus *Coregonus* (subgenus *Leucichthys*). Satisfactory keys for separating species of *Coregonus* (subgenus *Leucichthys*) do not exist and the validity of some species remains unsettled (Scott and Crossman 1973). To confound the problem, it has been suggested that various species may be introgressing (Wells and McLain 1973). The only adult *Leucichthys* that could occasionally be positively identified was the lake herring or cisco, *C. artedii*. Other *Leucichthys* and most juveniles were pooled as unidentified coregonids (code XC). This latter group was probably made up of *C. hoyi* (bloater) and a few *C. artedii*, as these are the most abundant species of *Leucichthys* in southeastern Lake Michigan (L. Wells, personal communication, Great Lakes Fisheries Laboratory, U.S. Fish and Wildlife Service, Ann Arbor, Mich.). Further discussion of current modifications in species composition and physical characteristics of *Coregonus* (subgenus *Leucichthys*) is presented later in this report (Unidentified Coregonids).

Difficulties were encountered in distinguishing between *Cottus cognatus* and *C. bairdi*, due in large degree to inexperience on the part of the identifiers. It is probable that of the specimens orginally identified as *C. bairdi* in 1973, the majority were actually *C. cognatus*, as this is the predominant species in samples taken from the study area. Some of the specimens identified as *C. cognatus* in 1974 may have been *C. bairdi*.

Data Manipulation and Calculations

Data from fish captured by seine, gill net, trawl and impingement were recorded directly on a 75-column coding form. For each fish the following information was recorded, one fish per line: date and time of sample, type of gear, night or day series, station, water temperature at fishing depth where gear was used, a species code, a unique incrementing number, length, weight, sex, gonad condition, presence or absence of food in the stomach and total time of set for gill nets. Special subsampling columns were used to designate the fish sampled from a larger group as well as columns to record the total weight of fish not examined (mass weight). A program was written to search the data for subsampled lots and then calculate the number of fish processed, the mean weight of those fish, and the number of fish present in the mass of fish not examined. The number of unsampled fish was assigned to length intervals proportionally, based on the number of measured fish found in length intervals. Fish were divided visually into many size classes when originally subsampled, to minimize error associated with this reconstruction of sample length-frequencies.

Fish data were keypunched, verified and read onto disk files and tapes. For the bulk of our numerical analysis we used the Michigan Interactive Data Analysis System (MIDAS) which was developed by the Statistical Research Laboratory at the University of Michigan. MIDAS has very efficient programs for collating data, calculating statistics and depicting graphical relationships (Fox and Guire 1973). From MIDAS, we obtained summary statistics and histograms on sex ratios, seasonal gonad conditions, temperature-catch relationships, length-frequency histograms and stomach contents.

Length-frequency histograms for the five major species included all fish captured by standard series nets. For trawls and seines numbers of fish in each interval represent the combined numbers from both replicates, while for gill nets the numbers represent the corrected number per 12 h in each interval. Months when no or very few fish were caught were sometimes eliminated from length-frequency histogram figures. Based on total length, fish were assigned to 10-mm intervals identified by their midpoint, e.g., fish in the 25-34-mm range were assigned to the 30-mm interval.

Gill net catches were adjusted to approximate numbers caught per 12 h by making the assumption that catch was a linear function of time. In the field, nets were set for as close to 12 h as possible, but the length of

time standard series gill nets were set ranged from 5.5 to 17.8 h and averaged 10.6 ± 0.3 (SE) h (N=82). It is known that the foregoing assumption is not completely valid as gill net catches per-unit-time might be expected to decrease as the net fills with fish, but the increased accuracy probably could not justify the cost of determining a precise relationship for each species.

Definitions

For purposes of this report a number of definitions were made. Fish larvae were arbitrarily designated as any fish 2.54 cm or smaller in total length, so that all fish longer than this will be treated in the adult and juvenile section. The seine and trawl collect some fish smaller than 2.54 cm and these fish are also treated in this section. Young-of-the-year was abbreviated as YOY and refers to newly hatched fish in their first year of life. In this same context, age-group 0 is sometimes used in discussions of the literature and is synonymous with YOY. Age-group 0, 1, 2, 3, etc., are mentioned occasionally and refer respectively to fish in their first year of life, second year of life, etc. Age designations change on 1 January. Other ambiguous terms used in this report are: offshore - usually refers to water depths greater than 21 m. In some instances when discussing seine catches, offshore indicates water depths greater than 2 m. Beach zone = surf zone -- water depths from 2 m to shore. Diel -- refers to the 24 h day. Diurnal -- activity by daylight, occurring every day; opposite of nocturnal.

RESULTS AND DISCUSSION

Fishing Effort

In order to determine yearly changes in natural fish populations, fishing efforts during each month and year of sampling should ideally be constant or at least comparable. We established the standard series stations to keep spatial sampling constant and attempted to sample these stations monthly with equal effort.

Standard series fishing effort in 1974 was about 8% greater than in 1973 (Table B4). Comparisons made in this report of total numbers caught between the 2 yr must be weighed with increased effort in mind. We believe the increased effort did not affect total numbers significantly, because most of the increase came during colder months (January, March, November and December) when fish abundance is low in the study area. The extra nets fished in colder months of 1974 collected less than 1% of the total catch.

Between April and October of both years fishing effort was approximately equal. Utilization of the study area by the majority of the fish populations was greatest during these months. Most comparisons in variability of fish numbers were made during April-October as were the statistical tests for temporal and spatial distribution.

Table B4. Total number of standard series nets fished during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan. A complete standard series each month was 36 (16 trawl hauls, 8 gill net sets and 12 beach seine hauls).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1973	0	6	15	35	36	36	35	36	35	36	16	1	287
1974	5	0	20	36	36	36	36	36	36	36	28	8	313

We concluded that fishing effort was comparable between the 2 yr of preoperational sampling. Variablility in total catch numbers will be discussed based on this premise. Discussions of winter catches will be tempered with the difference in effort between years.

General Diversity and Distribution of Fish Species

Between May 1972 and December 1974, 47 fish species representing 16 families were captured (by all fishing methods) from Lake Michigan in the vicinity of the Cook Plant (Table B5). Three species were captured only in 1972, two only in 1973, and three were first encountered during 1974. Thirty-one species have been captured every year. Five species have been taken only from the traveling screens of the Cook Plant's intake system.

Pooling our data with that from other generating station environmental studies, we estimate that the actual number of species occurring in the inshore waters of southeastern Lake Michigan is about 75 or 80. But some of these species are extremely rare or transients that normally inhabit streams, rivers, inland lakes, or protected bays. Preliminary analysis of 1975 (and limited 1976) data increased the total number of species caught by us to 59, indicating species composition of samples in the vicinity of the Cook Plant approaches the maximum diversity expected to be found in the study area. Total number of species and hybrids (splake, tiger trout, etc.) currently present in Lake Michigan is estimated to be 106, with an additional 17 species of which there is no catch record in the past 10 yr or so (L. Emery, personal communication, Great Lakes Fishery Laboratory, U.S. Fish and Wildlife Service, Ann Arbor, Mich.)

Our objective in sampling 2 yr before plant operation was to establish the natural temporal and spatial distribution and abundance of fish populations in the study area. To determine any plant operational effects on these populations we had to determine natural variability in fish numbers and distributions. Now that 2 yr of data have been collected we will, as one objective of this report, compare similarities and variations between years. To facilitate that objective the following will be a brief summary

Table B5. Scientific name, common name and abbreviations for all species of fish captured from Cook Plant study areas in southeastern Lake Michigan from May 1972 through December 1974. Fish were taken with netting gear unless otherwise noted. Names assigned according to Bailey et al. 1970. An X denotes presence in that year.

Scientific and common name	Abbreviation	1972	1973	1974
Acipenseridae				
Acipenser fulvescens Rafinesque Lake sturgeon	LG	X	X	X
Amiidae				
Amia calva Linnaeus[1] Bowfin	BF		X	
Clupeidae				
Alosa pseudoharengus (Wilson) Alewife	AL	X	X	X
Dorosoma cepedianum (Lesueur) Gizzard shad	GS	X	X	X
Salmonidae				
Coregonus artedii Lesueur Lake herring or Cisco	LH	X	X	X
Coregonus clupeaformis (Mitchill) Lake whitefish	LW	X	X	X
Coregonus hoyi (Gill) Bloater	BL	X	X	X
Prosopium cylindraceum (Pallas) Round whitefish	RW		X	
Oncorhynchus kisutch (Walbaum) Coho salmon	CM	X	X	X
Oncorhynchus tshawytscha (Walbaum) Chinook salmon	CH	X	X	X
Salmo gairdneri Richardson Rainbow trout	RT	X	X	X
Salmo trutta Linnaeus Brown trout	BT	X	X	X
Salvelinus namaycush (Walbaum) Lake trout	LT	X	X	X
Osmeridae				
Osmerus mordax (Mitchill) Rainbow smelt	SM	X	X	X

Table B5. continued.

Scientific and common name	Abbreviation	1972	1973	1974
Umbridae				
Umbra limi (Kirtland)[1] Central mudminnow	MM	X	X	X
Esocidae				
Esox lucius Linnaeus Northern pike	NP	X	X	X
Cyprinidae				
Couesius plumbeus (Agassiz) Lake chub	LC	X		
Cyprinus carpio Linnaeus Carp	CP	X	X	X
Notemigonus crysoleucas (Mitchill) Golden shiner	GL		X	X
Notropis atherinoides Rafinesque Emerald shiner	ES	X	X	X
Notropis hudsonius (Clinton) Spottail shiner	SP	X	X	X
Notropis stramineus (Cope) Sand shiner	SH			X
Pimephales notatus (Rafinesque) Bluntnose minnow	BM			X
Pimephales promelas Rafinesque Fathead minnow	PP		X	X
Rhinichthys cataractae (Valenciennes) Longnose dace	LD	X	X	X
Catostomidae				
Carpiodes cyprinus (Lesueur) Quillback	QL	X	X	X
Catostomus catostomus (Forster) Longnose sucker	LS	X	X	X
Catostomus commersoni (Lacepede) White sucker	WS	X	X	X
Moxostoma macrolepidotum (Lesueur) Shorthead redhorse	SR	X		
Ictaluridae				
Ictalurus melas (Rafinesque) Black bullhead	BB	X	X	X
Ictalurus natalis (Lesueur)[1] Yellow bullhead	YB			X
Ictalurus punctatus (Rafinesque) Channel catfish	CC	X	X	X

Table B5 continued

Scientific and common name	Abbreviation	1972	1973	1974
Percopsidae				
Percopsis omiscomaycus (Walbaum) Trout-perch	TP	X	X	X
Gadidae				
Lota lota (Linnaeus) Burbot	BR	X	X	X
Gasterosteidae				
Pungitius pungitius (Linnaeus) Ninespine stickleback	NS	X	X	X
Centrarchidae				
Ambloplites rupestris (Rafinesque) Rock bass	RB		X	X
Lepomis cyanellus Rafinesque Green sunfish	GN	X	X	X
Lepomis gibbosus (Linnaeus)[1] Pumpkinseed	PS	X	X	X
Lepomis macrochirus Rafinesque Bluegill	BG		X	X
Micropterus dolomieui Lacepede Smallmouth bass	SB	X		X
Micropterus salmoides (Lacepede) Largemouth bass	LB		X	X
Pomoxis nigromaculatus (Lesueur)[1] Black crappie	BC	X	X	
Percidae				
Etheostoma nigrum Rafinesque Johnny darter	JD	X	X	X
Perca flavescens (Mitchill) Yellow perch	YP	X	X	X
Stizostedion vitreum vitreum (Mitchill) Walleye	WL	X		
Cottidae				
Cottus bairdi Girard Mottled sculpin	MS	X	X	
Cottus cognatus Richardson Slimy sculpin	SS	X	X	X

[1]Impinged on Cook Plant traveling screens.

of the standard series catches in 1973 (for a more detailed discussion, see Jude et al. 1975).

Of the 31 species caught by standard series nets in 1973, five species numerically comprised slightly over 99% of the total catch (Table B6). Alewives were the dominant species in the study area, comprising approximately three-fourths of the total catch. Monthly catches varied considerably in terms of species and numbers caught; the majority of this variation was correlated with water temperatures, spawning activity and recruitment of young.

Although fishing effort was very low during December, January and February, nets that were fished indicated low numbers of fish present in the study area. Suckers, rainbow trout, burbot, smelt, yellow perch and spottail shiners made up the bulk of the winter catch.

As water temperatures increased in spring (March, April and May), numbers and species of fish caught increased considerably. Most fish caught in April were adults seeking warmer water and spawning areas (smelt, slimy sculpins). In May, numbers caught declined because the area of warmer water was greater, allowing populations to disperse; also adult smelt returned to deeper water after spawning.

Numbers of fish caught during summer (June, July and August) were moderate to very high because of spawning by warm-water species (alewife, spottail, yellow perch, trout-perch and johnny darter) and recruitment of YOY to standard series gear in August. Upwellings during the latter part of summer drastically affected spatial distributions by "forcing" (depending on the extent of the upwelling) some warm-water species out of the area or closer inshore and bringing in cold-water species (smelt, lake trout and bloater) with the colder water mass.

These upwelling effects were also noted in the catches at deeper stations in September. It was postulated that inclement weather, i.e., high waves, caused low catches of YOY in September beach seines. By November, the bulk of the populations had returned to deeper water except for lake trout which were seeking shallow spawning areas.

We believe the methods established in 1973 yielded valid data to analyze the distributions of fish populations in the Cook Plant study area. This year's data (1974) will help to further characterize and distinguish the natural fluctuations in populations. It will also further support or clarify assumptions and speculations made in the 1973 report. The following discussion will present 1974 findings and integrate them with 1973 data to expand on our preoperational data base.

Numbers of species caught by standard series fishing in 1974 were similar to those caught in 1973 (Table B7). Greatest monthly variations occurred during colder months of the year and were attributable to differences in fishing effort. For example, in December 1973, only one gill

Table B6. Number of fish caught in standard series nets (seines, gill nets and trawls) during 1973 in the inshore waters of southeastern Lake Michigan.

Species	Jan[1]	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Percent	Total
AL[2]	-	0	1894	10633	3251	6802	13246	79942	767	31855	5	0	76.31	148395
SP	-	15	441	2716	3394	7421	1737	2525	869	1434	128	1	10.63	20681
SM	-	4	124	4132	823	955	295	8401	1503	341	15	0	8.53	16593
YP	-	5	34	16	44	1497	650	949	257	398	27	0	1.99	3877
TP	-	0	1	47	157	1565	714	522	170	343	23	0	1.82	3542
JD	-	0	0	13	47	58	17	31	11	30	0	0	.11	207
WS	-	1	6	8	15	28	27	36	47	31	0	0	.10	199
LT	-	0	1	1	2	2	10	21	58	34	61	0	.10	190
XC	-	0	0	0	2	26	60	37	2	21	0	0	.08	148
LS	-	1	1	10	18	15	38	1	1	1	0	0	.04	86
RT	-	1	1	15	30	13	6	11	1	3	5	0	.04	86
SS	-	0	0	44	14	3	0	6	5	7	1	0	.04	80
BT	-	1	0	2	6	33	18	4	4	8	0	0	.04	76
ES	-	1	2	1	6	1	2	11	15	8	2	0	.03	49
LD	-	2	0	2	4	3	3	4	22	0	1	0	.02	41
NP	-	0	0	0	0	2	0	1	9	15	11	0	.02	38
CM	-	0	6	3	10	7	0	0	4	2	0	0	.02	32
CP	-	0	0	2	2	14	1	2	0	7	0	0	.01	28
CH	-	0	1	2	5	6	3	3	3	3	0	0	.01	26
GS	-	0	0	0	0	0	0	0	0	1	22	0	.01	23
NS	-	0	1	1	12	5	0	0	0	0	0	0	.01	19
MS	-	0	0	9	3	2	0	0	0	2	0	0	.01	16
CC	-	1	0	0	0	1	0	2	0	2	5	0	.01	11
BG	-	0	0	0	1	3	0	1	0	0	5	0	<.01	10
BR	-	0	0	4	0	2	0	0	0	0	0	0	<.01	6
LW	-	0	0	0	1	1	0	0	0	0	0	0	<.01	2
BB	-	0	0	1	0	0	1	0	0	0	0	0	<.01	2
PP	-	0	0	0	1	0	1	0	0	0	0	0	<.01	2
RB	-	0	0	0	0	1	0	0	0	0	1	0	<.01	2
GL	-	0	0	2	0	0	0	0	0	0	0	0	<.01	2
LB	-	0	0	1	0	0	0	0	0	0	0	0	<.01	1
Totals	-	32	2513	17665	7848	18466	16829	92510	3748	34546	312	1		194470

[1]See text for times when limited sampling (non-complete standard series) was performed.
[2]See Table B5 for definition of species abbreviations.

Table B7. Number of fish species caught with all standard series fishing gear in 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

	Month												Total Number of Species Caught Each Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1973	-	10	13	23	23	26	18	20	19	20	15	1	31
1974	5	-	17	23	23	23	17	20	15	21	17	9	32

	Season			
	Winter	Spring	Summer	Fall
	(Dec Jan Feb)	(Mar Apr May)	(Jun Jul Aug)	(Sep Oct Nov)
1973	10	27	28	24
1974	10	25	26	23

net was set, while in December 1974, eight gill nets were set. As fishing effort increases, the possibility of catching transient or sparsely distributed species increases. Although total number of species caught per month was similar in most months, the species were not always the same between the same month of the 2 yr. Most differences concerned less abundant species (species contributing less than 0.2% of the total catch) because of their rarity in the study area. Some of this variation will be discussed later under individual species.

To facilitate discussion, the year was arbitrarily divided into seasons (December of each year was grouped with January and February of that year). Seasonal catches for each year indicated few differences in total numbers of species during warmer months (Table B7). Greatest numbers of species occurred in summer which indicates the extensive utilization of the area by warm-water species for feeding, spawning and exploring for spawning areas. Some cold-water species were also present because of upwellings. A large number of species were observed in the spring, which was attributed to fish seeking their preferred water temperatures. Species numbers were lower in fall than spring and summer, apparently resulting from adults leaving the area after summer spawning activities. During winter months most species migrated to deeper water.

After collecting 2 yr of data we can make some general conclusions on seasonal species associations. Only four species (spottail shiner, yellow perch, white and longnose suckers) are found throughout the entire year in

the study area and two of these (spottail and perch) are caught in very low numbers during the coldest months (Table B8). These species evidently prefer shallower depths in the lake and do not migrate into very deep water in winter to seek warmer (4 C) water. Limited plant pumping in 1974 (see SECTION E) indicated that slimy sculpin were also present throughout the year, presumably in just the plant intake area. These fish probably represent a localized population of sculpins on the riprap and are not indicative of the lake-wide populations. Wells (1968) found sculpins only in water deeper than 12 fathoms from July to November. Our impingement data further indicate that channel catfish and gizzard shad were present near the intake during winter. YOY alewives were also present in December.

Many species were found from spring through fall (Table B8). The relatively colder water inshore during winter probably prevents these species from entering inshore areas. Species found during spring through fall and those present the entire year comprised numerically 99% of the total catches for 1973 and 1974 (total catch numbers will be discussed below in this section).

Species caught during only one or two seasons (Table B8) were utilizing the study area for three major reasons: (1) spawning, (2) seeking preferred water temperatures and (3) migrating through the area. Explanations and postulations for each species' presence in the study area will be discussed under individual species sections.

Alewives dominated the standard series total catch in 1974 (Table B9), but they were not present (in standard series catches) in colder months, January and December. Of the other 9 mo when fishing occurred, during seven of them alewives were the most abundant fish caught. Spottail shiners, the second most abundant fish caught during 1974, were collected during all months when fishing occurred. Although not as abundant as alewives, spottails were caught in considerable numbers during the summer. Alewives, spottails, smelt, yellow perch and trout-perch made up 98.5% of the total catch by number.

While found in low numbers, some of the other 27 species were caught consistently over many months. Johnny darter, slimy sculpin, brown trout, longnose dace, chinook salmon and especially white and longnose sucker were regularly caught throughout the year. Other species were abundant (or were found) only during a few months, while most species comprising 0.01% or less of the catch were caught in very low numbers, usually in only 1 or 2 mo.

August was the month of maximum catch in 1974. Young-of-the-year alewives and smelt and yearling spottails dominated catches at this time. The second highest monthly catch occurred in May and consisted mainly of adult and yearling alewives and spottails, and yearling smelt. Summer catches in June and July were moderately high because of the presence of sexually ripe adult alewives and spottails (ripe adult trout-perch and yearling yellow perch were also found in July).

Table B8. Generalized seasonal species associations in Cook Plant study areas. Groupings indicate when the bulk of the population we caught was present during 1973 and 1974. Some species found in more than one season may be present in greatest numbers only during certain months. Rarely caught species are not included.

Present entire year
- Spottail shiner (low numbers in winter)
- Yellow perch (low numbers in winter)
- White sucker
- Longnose sucker

Present spring through fall
- Alewife (few present in winter)
- Smelt (few present in winter, adults only in spring, present in summer only during upwellings)
- Trout-perch (few present in winter)
- Johnny darter (localized population on the riprap present all year)
- Lake trout (most present in fall)
- Slimy sculpin (localized population on the riprap present all year)
- Brown trout
- Emerald shiner
- Longnose dace
- Chinook salmon
- Northern pike

Present spring and summer
- Coho salmon
- Carp
- Ninespine stickleback

Present in spring
- Rainbow trout
- Burbot (some present in winter)
- Black bullhead (few present in winter)
- Mudminnow (may be a localized population on the riprap)

Present in summer
- Coregonids (only during upwellings, few present in spring and fall)
- Bluegill

Present in fall and winter
- Gizzard shad (some present in early spring)
- Channel catfish (few present in spring and summer)

Table B9. Number of fish caught in standard series nets (seines, gill nets and trawls) during 1974 in the inshore waters of southeastern Lake Michigan.

Species	Jan[1]	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Percent	Total
AL[2]	0	-	282	4832	14296	3758	4662	36673	8179	2875	725	0	66.81	76281
SP	1	-	167	313	4112	6898	5848	6047	414	476	36	22	21.31	24334
SM	0	-	55	701	794	59	385	3304	93	346	13	5	5.04	5755
YP	1	-	14	35	14	156	2580	1181	453	9	75	16	3.97	4534
TP	0	-	0	10	145	55	928	128	106	187	17	2	1.38	1578
JD	0	-	0	5	93	86	60	6	7	22	14	0	0.26	293
SS	0	-	2	155	19	15	14	28	2	18	19	0	0.24	272
XC	0	-	0	0	0	3	199	7	1	15	0	0	0.20	225
CM	0	-	8	8	71	13	2	26	0	0	25	0	0.13	153
WS	2	-	2	3	16	19	29	13	16	13	5	8	0.11	126
LT	0	-	1	1	17	9	0	0	0	12	85	0	0.11	125
LS	1	-	2	4	26	11	39	2	3	3	6	2	0.09	99
GS	0	-	5	4	44	1	0	1	20	9	0	0	0.07	84
BT	0	-	3	5	14	13	6	5	2	1	2	0	0.04	51
BG	0	-	1	0	40	5	0	0	0	0	0	0	0.04	46
LD	0	-	2	1	3	8	2	1	0	20	6	0	0.04	43
CH	0	-	0	3	6	3	6	6	13	0	3	1	0.04	41
CP	0	-	0	2	7	0	1	9	5	3	0	0	0.02	27
NS	0	-	0	1	15	4	3	1	0	0	0	0	0.02	24
CC	0	-	0	1	0	1	8	0	5	1	1	0	0.02	17
NP	1	-	3	3	1	2	0	1	0	5	0	0	0.01	16
BR	0	-	1	1	2	1	0	0	0	0	0	10	0.01	15
ES	0	-	2	1	1	3	0	0	0	6	0	0	0.01	13
RT	0	-	5	2	0	0	0	0	0	0	1	0	0.01	8
GN	0	-	0	0	5	0	0	0	0	1	0	0	0.01	6
SH	0	-	0	0	0	0	0	0	0	3	1	0	< 0.01	4
BB	0	-	0	1	1	0	0	0	0	0	0	0	< 0.01	2
LW	0	-	0	0	0	0	0	1	0	0	0	0	< 0.01	1
GL	0	-	0	0	0	0	0	1	0	0	0	0	< 0.01	1
LB	0	-	0	0	0	1	0	0	0	0	0	0	< 0.01	1
LH	0	-	0	0	0	0	0	0	0	0	0	1	< 0.01	1
BM	0	-	0	0	0	0	0	0	0	1	0	0	< 0.01	1
Totals	6	-	555	6092	19742	11124	14772	47441	9319	4026	1033	67		114177

[1]See text for times when limited sampling (non-complete standard series) occurred.
[2]See Table B5 for definition of species abbreviations.

After high catches in summer, numbers of fish collected declined progressively in September, October and November. Most adults migrated out of the study area after spawning and YOY numbers decreased because of migrations and natural mortality. Although fishing effort was low during December and January, the very low catches demonstrated the scarcity of fish during winter in the study area (impingement data also corroborated this finding). As water temperatures increased during March and April, catches increased because fish migrated into the warmer waters inshore.

Although standard series fishing effort was similar between 1973 and 1974, there were approximately 80,000 fewer fish in the 1974 total catch (Tables B6 and B9). These fish represented a 41.3% decline in total catch and is an indicator of variability in the system. Even though there was considerable variation in total catch between years in several of the less abundant species, most of the 41% decline can be accounted for by the catch of two of the most abundant species, alewives and smelt (Tables B6 and B9).

In 1974, approximately 70,000 and 10,000 fewer alewives and smelt respectively were caught. Most of the decline in alewives was caused by decreased seine catches of YOY in late summer and fall. While beach seine catches are generally quite variable, the decline may be due to decreased spawning success in the study area in 1974 compared to 1973. During seining in August 1974, an upwelling occurred and may have "forced" alewife YOY out of the area and decreased catches. Lower smelt catch in 1974 was attributed to two occurrences. Considerably fewer adult smelt were caught in April 1974, compared to April 1973. We may have missed the spawning run when sampling occurred or the number of adults spawning was low in the study area during 1974. Poor spawning was probably the cause of the 1974 decline because numbers of YOY smelt caught in late summer and fall, 1974, were much lower than comparable 1973 catches. Low catches of YOY also contributed to the lower total smelt catch in 1974.

With 2 yr of data accumulated, some comparisons and conclusions can be made on seasonal catches between the 2 yr of preoperational data. By grouping months into seasons according to generalized water temperature changes, the following categories were established: spring (March, April, May)--generally rising water temperatures; summer (June, July, August)--highest temperatures for the year; fall (September, October, November)--generally decreasing temperatures; and winter (December, January, February)--lowest temperatures for the year (note that during winter, December was grouped with January and February of the same year to facilitate yearly comparisons). The majority of the total catch was caught during summer of both years (Table B10). While numbers of fish caught during summer of the 2 yr were different, the percentages of the total catch were very similar, 66 vs. 64 (numbers in monthly catches will be discussed later).

There was some variation between catches in spring and fall of the 2 yr. Catches in fall of 1973 contributed more to the year's total catch than 1974 fall catches contributed to that year's total. More YOY alewives and

Table B10. Percentages by number of the total standard series catch of fish taken in each season of the year, 1973-1974 in Cook Plant study areas, southeastern Lake Michigan. December of each year was grouped with January and February of the same year.

	Spring (Mar Apr May)	Summer (Jun Jul Aug)	Fall (Sep Oct Nov)	Winter (Dec Jan Feb)
1973	14.4	65.7	19.9	<0.1
1974	23.1	64.2	12.6	0.1

smelt were caught during summer and fall 1973 than in fall 1974 and caused most of the above differences in fall comparisons. Because of the larger summer and fall catches in 1973, the spring catch percentage was lower in 1973, compared to 1974. Percentages contributed by winter catches in both years were an insignificant portion of the year's total catch.

Since spring and fall proportions of the total catch varied somewhat between years, an attempt was made to examine monthly catches to further explain the variation. Because the 2 yr total catches were quite different (Tables B6 and B9), monthly catches will be compared as percentages of the year's catch.

Catches from May, September and October varied considerably between 1973 and 1974 (Fig. B2). Because alewives dominated most monthly catches, any fluctuations in their numbers correspondingly caused considerable variation in monthly catches between years. Fluctuations in alewife numbers caused the May, September and October catch variability between years.

Approximately twice as many alewives were captured in April 1973, compared with April 1974, and approximately four times as many alewives were caught in May 1974, compared with May 1973. In 1973, alewife catches increased in April, declined in May and increased again in June. Fish migrated into the inshore warmer waters in April, then dispersed into increased warmer water mass in May. Alewives then returned in large concentrations in June to spawn. In 1974, spring catches did not peak until May, demonstrating that the spring inshore migration occurred later in 1974 (May) than in 1973 (April). Reasons for this temporal variation are probably related to inshore water temperature changes.

While water temperature data are presented here for the discussion of total catch, a detailed discussion of the temperature data will follow for later reference to other sections. To facilitate comparisons of temperature between years, daily lake temperatures over a considerable period were needed; therefore municipal water intake data from the St. Joseph Municipal

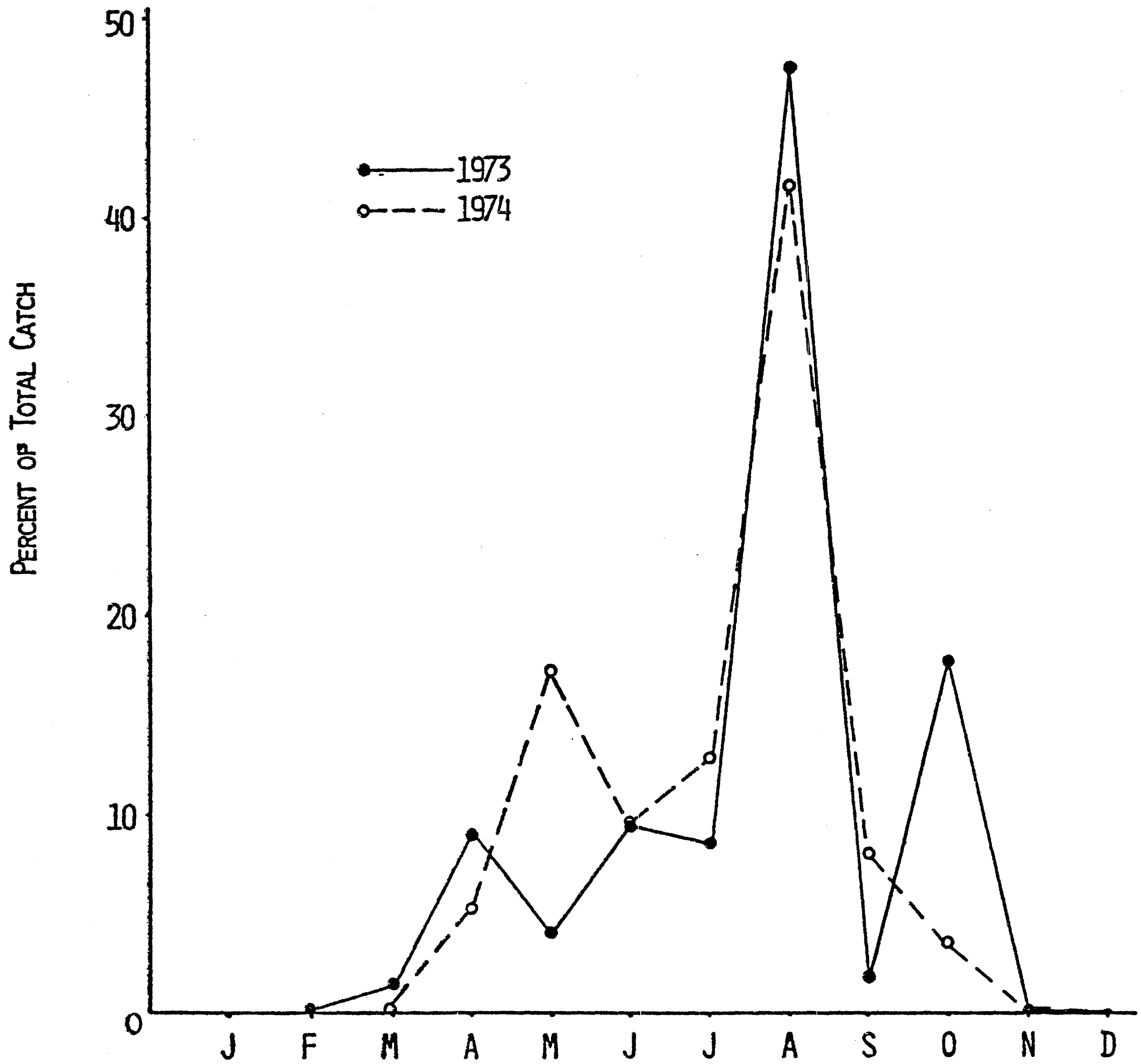


Fig. B2. Percentage of each month's contribution to the total standard series catch of fish from Cook Plant study areas, southeastern Lake Michigan, 1973 and 1974.

Water Plant were used for this discussion. Although the Cook Plant is 14.7 km south of the St. Joseph Plant, water temperatures are probably similar between the two areas. Local variations, e.g., upwellings, may cause short-term differences in temperature between the two areas, but only seasonal and yearly trends and variations were determined from the St. Joseph data and discussed below. We record temperatures at time of sampling and plant personnel record water temperatures, but these data are too short-term and sporadic for comparative purposes. Other temperature data used in this report were recorded at the study areas.

Graphically, the 20-yr average of daily lake temperatures was a bell-shaped curve as expected (Fig. B3). Temperatures were lowest in January and February and began to rise in March. Inshore temperatures did not surpass the 4 C mid-lake bottom temperature until the first week of April. This has significant implications for our study area because fish overwintering in deep water now have warmer water inshore to inhabit. Water temperatures continued to increase from May through July, although the rise was not as steep as in April. Maximum temperatures were reached in August and continued to the beginning of September. At this time there was considerable variation in daily temperature, probably caused by the frequent upwellings which occur during these months (see Seibel and Ayers 1974 for a detailed analysis of upwellings in the study area). From September through December, there was a steady decline in water temperatures.

During some months of 1973, water temperature varied considerably from the 20-yr average (Fig. B4). Temperatures in 1973 rose considerably during March and stayed above 4 C. June temperatures were clearly above the 20-yr average for that month. From June to September, several upwellings occurred; during five of them, temperatures declined sharply (e.g., on July 9, 1973, the average temperature was 24.7 C and on July 11, 1973, the average was 9.9 C). In September, temperatures were considerably below the 20-yr average, while in October temperatures were above average.

As in 1973, temperatures during some months of 1974 varied considerably from the 20-yr average (Fig. B5). Temperatures during March were above the average; however, they did not stay consistently above 4 C. July, August and September temperatures were below the 20-yr average. Again in 1974, as in 1973, several upwellings occurred during June through September. The 1974 upwellings were generally not as precipitous as those in 1973.

Average monthly temperatures for 1953-1972, 1973 and 1974, again point out the variation between 1973 and 1974 with the 20-yr average (Fig. B6). In 1973 considerable deviation from the 20-yr average occurred during March, June, September, October and December. Except for January and September, all months of 1973 were above the 20-yr average, which indicates the weather in 1973 was warm and very mild. Summer temperatures in 1973 were considerably above summer 1974 temperatures. March, August and September of 1974 deviated considerably from the 20-yr average.

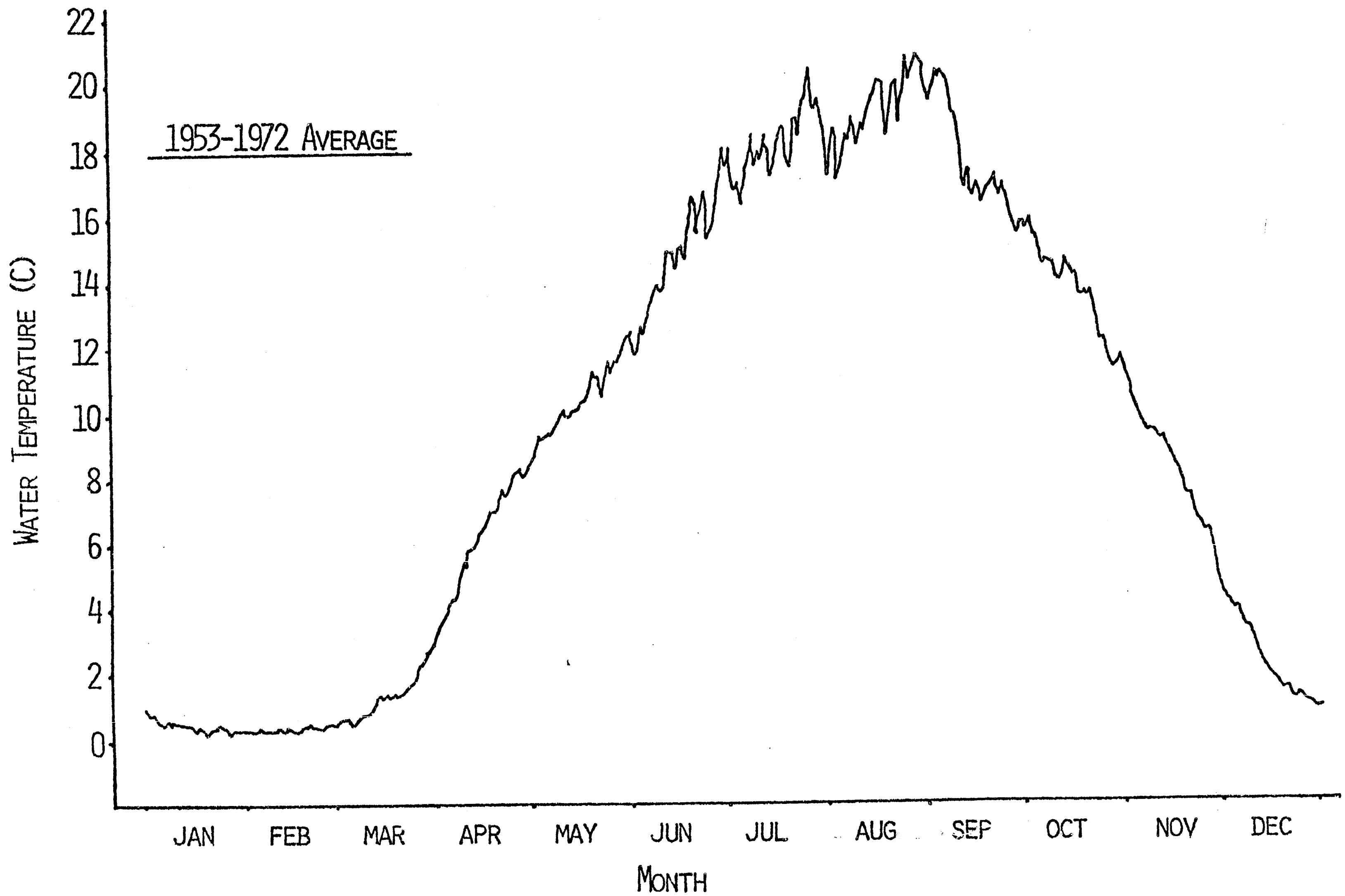


Fig. B3. Twenty-year average (1953-1972) Lake Michigan water temperatures. Data are from the St. Joseph Municipal Water Plant for raw Lake Michigan water (intake depth 6 m). Temperature was recorded once per day. February 29 was deleted from the graph.

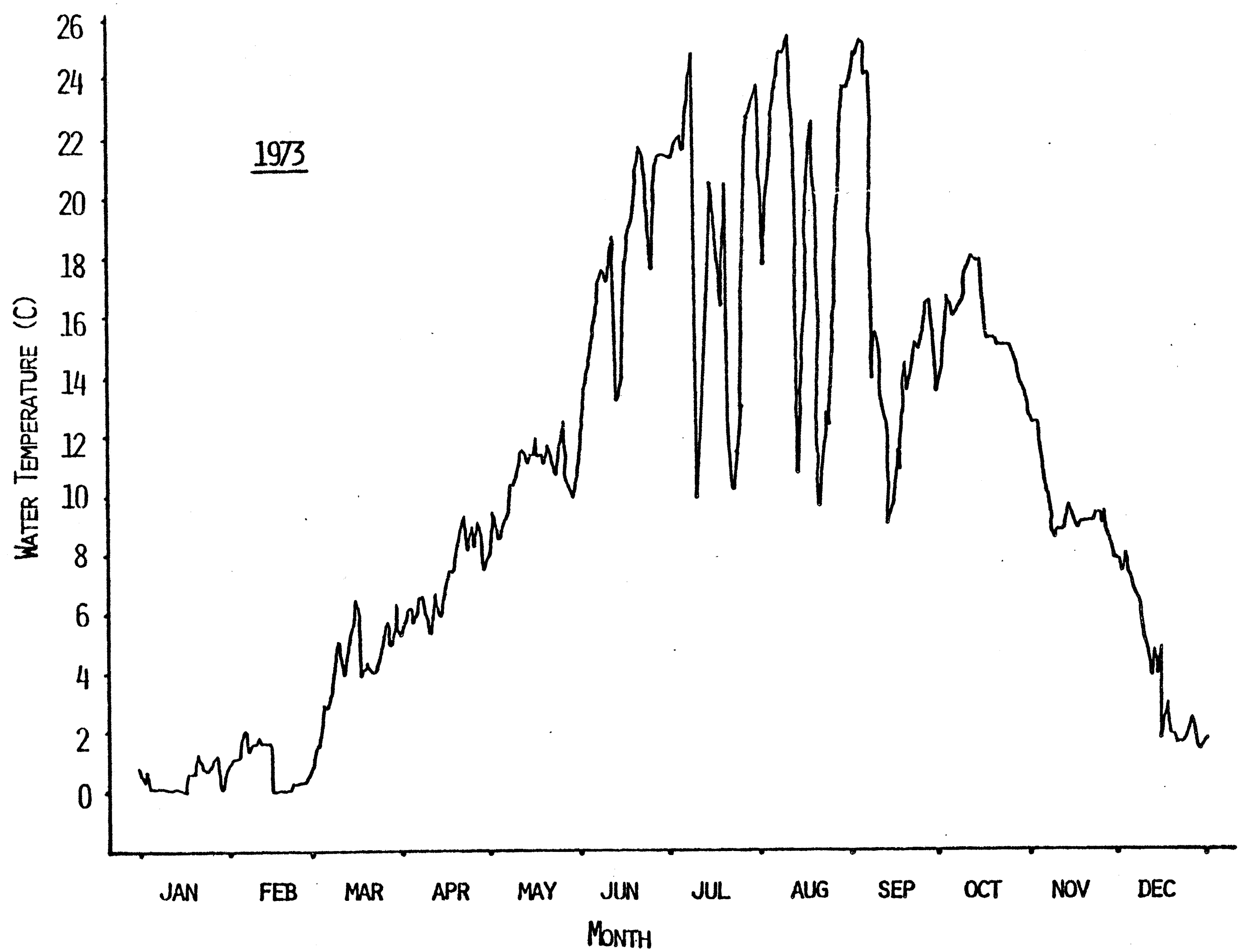


Fig. B4. Daily Lake Michigan water temperatures for 1973. Data are from the St. Joseph Municipal Water Plant for raw Lake Michigan water (intake depth 6 m).

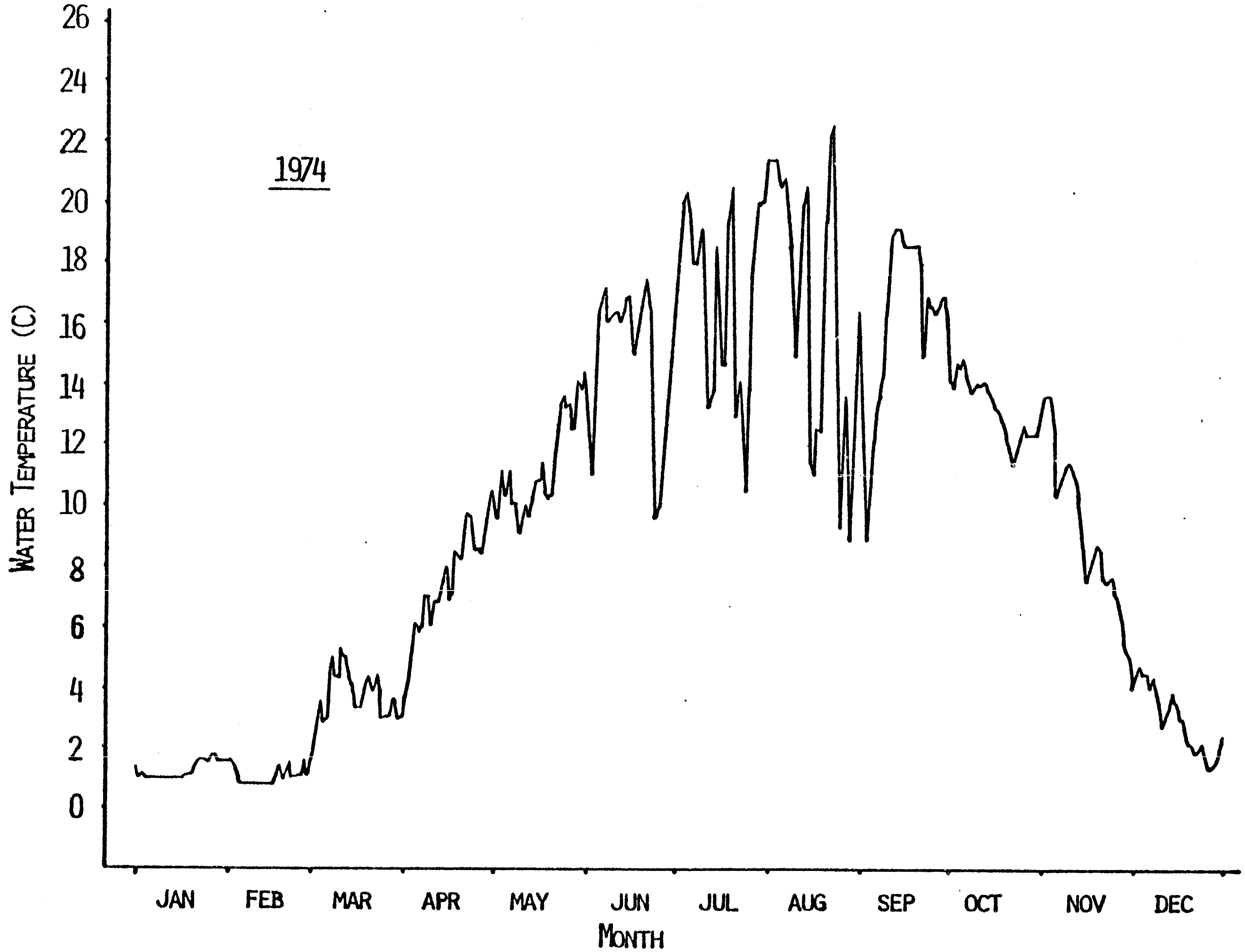


Fig. B5. Daily Lake Michigan water temperatures for 1974. Data are from the St. Joseph Municipal Water Plant for raw Lake Michigan water (intake depth 6 m).

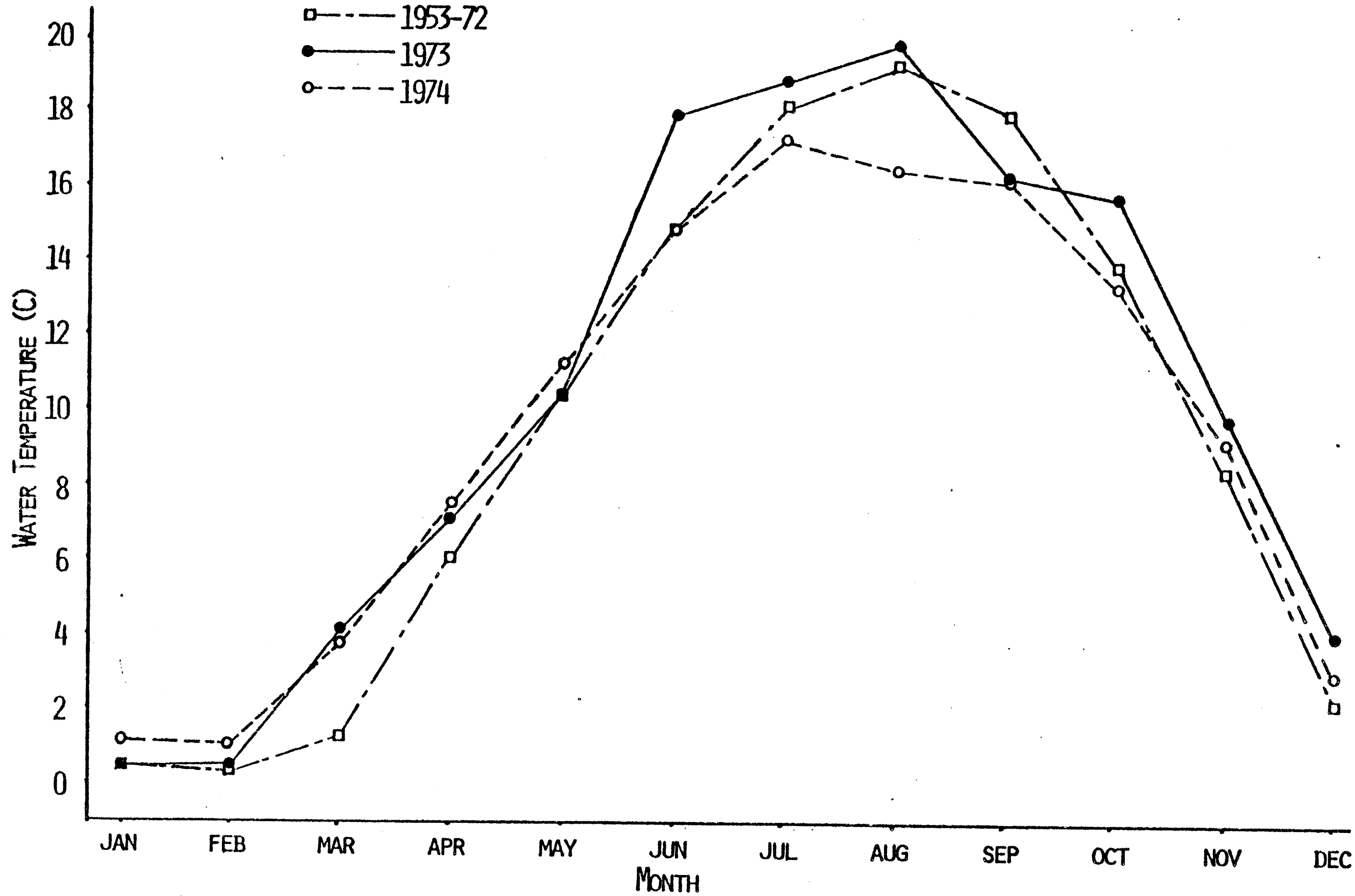


Fig. B6. Monthly average water temperatures for 1953-1972, 1973 and 1974. Data are from the St. Joseph Municipal Water Plant for raw Lake Michigan water (intake at 6 m).

Using the data from the discussion above, we can develop some theories as to causes for catch variability between 1973 and 1974. Warm weather in March 1973 caused inshore water temperatures to reach 4 C early in March; temperatures continued to rise in April. The large alewife catch in April 1973, occurred approximately 40 days after 4 C water temperatures were consistently reached. In 1974, the 4 C temperature was reached in early April and the large alewife catch in May occurred approximately 45 days later. It appears the alewives concentrate inshore 40 to 45 days after inshore water temperature has reached and stayed consistently above 4 C. This time-period theory was substantiated somewhat by the fact that in April 1974, sampling occurred approximately 16-18 days after temperatures reached 4 C, but the alewife catch was not large. Using temperature data for the 20-yr average would give mid-May as the period when alewives would "normally" concentrate inshore during their spring migration. Of course, the schooling nature of alewives (causing patchy distribution) and vertical migrations may be a factor in catch variation. Future sampling may help to verify or disprove this theory.

Continuing the discussion of 1973-1974 monthly catch comparisons, September and October catches will be considered next. September and October catches varied considerably between 1973 and 1974 (Fig. B2). Again as in May, fluctuations in the catch of alewives, mostly seine catches of YOY, caused the September and October variability.

Very few YOY alewives were seined in September 1973, while several thousand were seined in September 1974 (these data and further discussion of their variability will be presented under the alewife section). The extremely low catch in September 1973 was caused by high waves forcing the fish from the beach zone; YOY were seined in July, August and October. In 1974, weather conditions were fair during September sampling and YOY were seined.

Considerable variation occurred in the seine catches of YOY alewives during October of the 2 yr. In contrast to September, the October 1973 catch was higher than the October 1974 catch. High waves were encountered during October 1974 seining, but apparently the beach zone was not completely inhospitable for YOY. We believe the lower catch in fall was due to a lower local population of YOY in 1974 compared to 1973. Seine catches of YOY in July and August were much higher in 1973 than 1974. Evidently spawning and hatching success of alewives was greater in 1973 than in 1974 in the study area or mortality of newly-hatched fish was greater in 1974. Warmer temperatures in June, July and August probably contributed to the increased recruitment in 1973. Part of the reason for lower 1974 seine catches of YOY alewives may be related to an upwelling which occurred in August 1974 during sampling. This upwelling dropped temperatures substantially in the beach zone and may have "forced" the fish to other areas in the lake.

The above discussion was given as an overall view of the total catch of adult and juvenile fish. Seasonal and monthly variation within a sampling

year and between years was analyzed subjectively to point out and explain gross variations which occurred. The following discussion will concern the contribution each gear type made to the total catch to further analyze the variations which occurred in the distribution of total catch between years.

Day and Night Catches by Gear Type

As we discussed in the 1973 report (Jude et al. 1975), each fishing gear varies in its ability to catch juvenile and adult fish. Consequently, we use three types of gear to complement each other and collect samples which are representative of all sizes and species present in the study area. One difficulty in sampling the 6- and 9-m stations is that the gear at best only samples the bottom 2 m. Therefore, we may underestimate abundance of pelagic species, e.g., alewives, smelt, emerald shiner, coho and chinook salmon, in the upper water strata. The degree of this underestimation is unknown, but we believe the cost and time involved in sampling the upper strata does not warrant the effort weighed against the added knowledge gained. Because methods are standardized between months and years, we assume that gear efficiency did not change and therefore catch variation was caused by changes in distribution or population numbers.

Some indications of fish distribution and behavior can be gained by examining the numbers and percentages of fish caught by day and night fishing with the three gear types (Tables B11 and B12). Also, gear bias for individual species can be revealed by examining these data.

Seines --

Of the three gear, seines accounted for 73% in 1973 and 64% in 1974 of the total yearly catches. Day seining accounted for the majority of the total seine catch (Table B11). These data reveal the great abundance of fish utilizing beach zone waters in the study areas. The numerical majority of these fish were YOY alewives with some YOY spottails and yellow perch. Undoubtedly the beach zone is an important nursery area for these species.

Habitat diversity and attractiveness to fish was amply demonstrated by the total number of species collected in Cook Plant beach zones (28 in 1973 and 29 in 1974). Trawling accounted for 20 different species in 1973 and 18 in 1974, while gillnetting accounted for 19 in 1973 and 21 in 1974. Of the total number of species collected by standard series nets during both years, all species except for burbot, lake whitefish and lake herring were collected (at least once) by seining. Certainly the dynamic and diverse nature of the beach zone compared to the rest of the inshore lake habitat make this an important area for most of the fish found in the inshore waters. At least one life stage of each fish species found in inshore waters utilizes the beach zone.

The attractiveness of the beach zone to many fish species is not understood, but some suppositions can be given. Shallow depths may be a protective aid for young fish, with predators unable to make effective attacks in shallow water. Sand bars near shore create long pools which may

Table B11. Number and percentage of fish caught during the day in standard series seines, gill nets and trawls during 1973-74 at Cook Plant study areas, southeastern Lake Michigan.

	Seine				Gill Net				Trawl			
	1973		1974		1973		1974		1973		1974	
Species	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
AL[1]	102307	90	45901	75	6017	5	5007	8	5715	5	10348	17
SP	8908	79	12096	90	1396	12	522	4	947	8	876	7
SM	847	9	64	3	321	3	167	9	8817	88	1723	88
YP	284	12	1348	63	1073	47	639	30	925	41	163	8
TP					22	3	25	4	791	97	611	96
JD	3	5	1	2					53	95	61	98
WS	6	10	3	11	49	79	23	85	7	11	1	4
LT			1	9	32	97	10	91	1	3		
XC	1	2	2	2	15	28	15	13	38	70	101	86
LS	1	4	1	2	20	87	48	98	2	9		
RT	35	97	4	100	1	3						
SS									19	100	27	100
BT	14	70	16	59	6	30	11	41				
ES	33	100	9	100								
LD	5	100	9	100								
NP	3	14	1	11	19	86	8	89				
CM	3	33	22	47	6	67	25	53				
CP	4	80	8	50	1	20	7	44			1	6
CH	5	63	9	82	2	25	1	9	1	13	1	9
GS	6	100	4	40			6	60				
NS			1	14					1	100	6	86
MS									1	100		
BG	1	100	33	100								
CC	1	50	4	80			1	20	1	50		
BR					3	100	3	100				
LW									1	100		
BB			1	100								
PP	2	100										
RB												
GL			1	100								
LB			1	100								
LH							1	100				
GN			5	100								
SH			3	100								
BM												
Total	112469		59548		8983		6519		17320		13919	
Percent of Year's Total		57.8		52.2		4.6		5.7		8.9		12.2

[1]See Table B5 for definition of species abbreviations.

Table B12. Number and percentage of fish caught at night in standard series seines, gill nets and trawls during 1973-74 at Cook Plant study areas, southeastern Lake Michigan.

	Seine				Gill Net				Trawl			
	1973		1974		1973		1974		1973		1974	
Species	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
AL[1]	22651	66	4808	32	5242	15	4392	29	6463	19	5825	39
SP	4813	51	6645	61	2314	25	2123	20	2303	24	2072	19
SM	1657	25	251	7	247	4	135	4	4704	71	3415	90
YP	342	21	2010	84	517	32	224	9	736	46	150	6
TP	80	3	21	2	259	10	217	23	2390	88	704	75
JD	4	3	3	1					147	97	228	99
WS	25	18	4	4	108	79	90	91	4	3	5	5
LT					154	98	110	97	3	2	4	4
XC					69	73	45	42	25	27	62	58
LS	2	3	2	4	58	92	46	92	3	5	2	4
RT	48	96	3	75	2	4	1	25				
SS	8	13	23	9			1	1	53	87	221	90
BT	54	96	11	46	1	2	11	46	1	2	2	8
ES	16	100	4	100								
LD	36	100	34	100								
NP	2	13	3	43	12	75	4	57	2	13		
CM	6	26	28	26	17	74	78	74				
CP	16	70	4	36	7	30	6	55			1	9
CH	5	28	5	17	13	72	22	73			3	10
GS	17	100	50	68			24	34				
NS	10	56	3	18					8	44	14	82
MS	3	20			1	7			11	73		
BG	8	89	10	77					1	11	3	23
CC	2	22	6	50	7	78	3	25			3	25
BR					2	67	11	92	1	33	1	8
LW							1	100	1	100		
BB	2	100	1	100								
PP												
RB	1	50			1	50						
GL	2	100										
LB	1	100										
LH												
GN			1	100								
SH			1	100								
BM			1	100								
Total	29811		13932		9031		7544		16856		12715	
Percent of Year's Total		15.3		12.2		4.6		6.6		8.7		11.1

[1] See Table B5 for definition of species abbreviations.

effectively (at least for the first sand bar from shore) prevent large predatory fish from entering the area. Influxes of various materials such as nutrients and organic matter (e.g., terrestrial insects) from the land and surface runoff (i.e., rivers and streams) may make this area attractive to some species. It may also be that species migrating through the area or those searching for rivers and streams would be moving close to shore and therefore be vulnerable to seining.

Emerald shiners and longnose dace were caught only by seining (Tables B11 and B12). Longnose dace probably reside exclusively in the beach zone when present in the inshore waters, while other gear may not be sampling the pelagic emerald shiner. Several other species--black bullhead, fathead minnow, golden shiner, largemouth bass, green sunfish and bluntnose minnow were caught only by seining, but in very low numbers. They are probably transients rather than exclusive inhabitants of the beach zone. Juveniles of several species (rainbow and brown trout, carp, chinook and coho salmon, channel catfish, gizzard shad and bluegill) were also caught in large numbers by seining compared to the total catch of each species in all gear. Again, the attractiveness of the beach area to young fish is apparent.

Considerably more fish were caught during day seining than during night seining. Catches of YOY alewives and spottails caused most of this difference. These fish evidently return to deeper water at night after inhabiting the beach zone during the day. Reasons for this behavior pattern are unknown, but possibly the young fish stay inshore during the day to avoid predators. At night they move out of the beach zone to feed on zooplankton in deeper water. Also, effective attacks by sight feeding predators are probably diminished at night. The slight drop in temperature at night in the beach waters might also have been a factor in this behavior.

While fewer alewives were caught by seining in 1974 compared to 1973 (better hatching success in 1973 was probably the cause), catches of spottails and yellow perch were greater in 1974. One reason for the greater seine catch of spottails was that the large 1973 year class returned as juveniles in 1974, causing larger catches. This did not occur with alewives because most juveniles do not return to the inshore waters but stay at mid-depths during their second summer of life. The increased yellow perch seine catch in 1974 was also probably due to a good 1973 year class returning as juveniles in 1974. Apparently, the 1972 year class of perch was not large because fewer juveniles were caught in 1973. The seine catch of smelt was lower in 1974 compared to 1973. Large numbers of ripe smelt adults were caught in April 1973, but very few were caught in April 1974. Apparently sampling in 1973 coincided with the spawning run while in 1974 it did not.

Although overall numbers of fish caught by seining were lower in 1974, there were very few differences in percentages caught between the 2 yr. Minimal yearly difference is a very good indication that gear efficiency did not change and methods are well standardized between years.

Gill nets --

Total numbers of fish caught by gillnetting were also lower in 1974 than in 1973 (Tables B11 and B12). Percentages of fish caught by gillnetting compared to the total catch from all gear were slightly higher in 1974 because of the lower seine catch. Lower gill net catches of the five most abundant species indicate a general overall decline in adult abundance during 1974 in the study area. This decrease was probably related to generally cooler temperatures occurring in 1974. (More discussion on this point will follow later.)

Gill nets are generally biased towards collecting larger species and larger individuals of a given species, and our gill net catches reflected this partiality. Adults of large species (yellow perch; white and longnose suckers; lake, rainbow and brown trout; northern pike; chinook and coho salmon; channel catfish; burbot; lake whitefish; and lake herring) were caught in greatest numbers by gillnetting. While trawling was performed in the same areas and depths as gill net sets, very few of the above species were caught (except for small yellow perch). Such a catch difference is strong evidence of the need for using different fishing gear to adequately sample populations in a given area.

While some species are very vulnerable to gill nets, three species found in the study area were not susceptible. Johnny darter, slimy sculpin and ninespine stickleback were caught in moderate numbers by trawling, but only one fish (a slimy sculpin) was ever gillnetted. Small size and benthic behavior probably prevents these species from being gillnetted.

During both years more fish were gillnetted at night than during the day. One reason for decreased day catches is that fish can probably sense the nets better during the day and are therefore more susceptible at night. Nocturnal behavior by some species also caused increased night catches. Trout-perch were definitely more active at night in the study area and very high night catches reflected this. Lake, brown and rainbow trout, chinook and coho salmon, white suckers and bloaters entered the study area in greater numbers at night which led to increased night catches. Spottail shiners were also more active at night which was reflected in increased night catches. In contrast to nocturnal behavior, substantially larger catches of yellow perch during the day indicate more diurnal behavior by this species.

Trawls --

Differences between total day and night trawl catches were not as great as differences in day and night seine catches (Tables B11 and B12). Although overall total catch variation was small, there were substantial differences in day and night catches of some species.

Considerably more alewives were caught by day trawling than by night trawling in 1974, while in 1973, there was little difference. Much of the day-night difference in 1974 was due to large day catches of adults in May.

Night trawl catches of spottails were higher than day catches, which was also shown by gill net catches. Seine catches, however, were higher during the day. Spottails must concentrate in the beach zone during the day and then move farther offshore at night into the 6- and 9-m depths where trawling and gillnetting occurred. This activity pattern was found in 1973 (Jude et al. 1975) and is substantiated by 1974 data.

Night trawl catches of all species combined were higher than day catches in 1974 but the opposite occurred in 1973. Very large day catches of YOY smelt in August and September 1973 caused most of this variation. Night trawl catches of trout-perch were high in 1973, but were lower in 1974. Very high night catches of trout-perch occurred in June 1973, but were not found in June 1974. We suspected that fish may have been concentrated to spawn in June 1973, but this is speculative. It is possible that peak spawning occurred later than June in 1974, but the exact reasons for the variation between years is unknown.

Higher night trawl catches of johnny darters, slimy sculpins and ninespine sticklebacks were recorded during both years. These species are more active nocturnally in the study area.

Both seine and gill net total catches (day and night) were lower in 1974 than in 1973; trawl data also showed this overall decrease. Dissimilarities in water temperatures between the 2 yr were suspected as the cause for the lesser abundance in 1974 (more discussion of this will follow).

Monthly Catches by Gear Type

Trawls --

Trawl catches were quite variable between months and years (Fig. B7). Both distribution and population fluctuations contributed to this variation. Although a monthly total trawl catch may consist of more than 10 species, the vast majority of the catch (numerically) usually consisted of two, three or four species. Therefore, a population or distribution change in one or more of these species will affect total catch considerably. While statistical and detailed analysis of the trawl catches of abundant species will be presented later, some observations on gross changes in total trawl catch can be made.

In 1974, the total trawl catch for April (all species) was above average (Fig. B7). Alewives and some spottails were beginning to migrate inshore, while some smelt were beginning to seek spawning areas. The May trawl catch was highest for the year predominantly because of alewives, but many spottails and some trout-perch were also concentrating inshore in preferred water temperatures at this time. Smelt were also caught in May because the last of the spawning run was occurring. The low trawl catch in June was unexpected; possibly alewives were spawning closer to shore. Trawl catch increased in July possibly because of spawning alewives, spottails and especially trout-perch. The August trawl catch increased over the July catch because of large catches of YOY smelt. The very low catch in

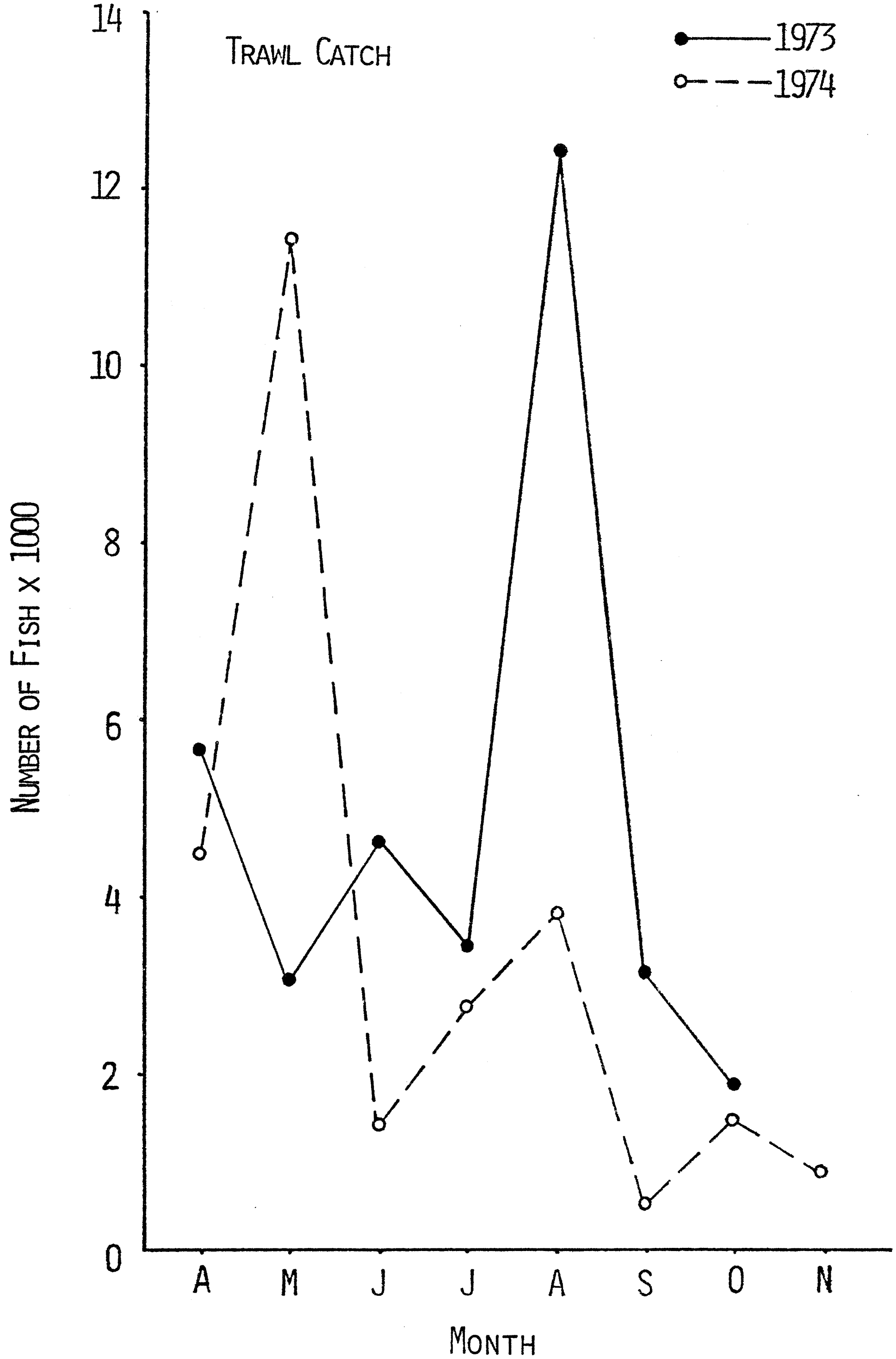


Fig. B7. Total number of fish caught by standard series trawls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

September is unexplainable, while low catches in October and November indicate that most species were migrating out of the study area for deeper water. Temporal distribution changes in 1974 (discussed above) did not closely follow patterns observed in 1973.

The differences in trawl catches between months in 1973 and 1974 indicate the wide natural variation in the distribution of fish species in the study area (Fig. B7). This natural distribution variation makes it extremely difficult to detect numerical population changes. Except for May, all months of 1973 had trawl catches which were higher than in 1974. Since the five most abundant species i.e., alewife, spottail shiner, smelt, yellow perch and trout-perch constituted approximately 98% and 97% of the total catches in 1973 and 1974 respectively, we can concentrate on numerical changes in these fishes to explain monthly total trawl catch variation. While approximately 4000 more alewives were caught in trawls in 1974, there were approximately 300, 8400, 1100 and 1900 fewer spottails, smelt, yellow perch and trout-perch respectively caught by trawling in 1974. Some explanations can be given for these changes, but in general the reasons are quite speculative.

The increased 1974 over 1973 alewife catch was partly the result of the large spring concentration which occurred in May 1974. Trawling in May apparently coincided quite closely with the concentration. In 1973, peak alewife concentration did not occur at the time and in the area of trawling and catch was lower. This was a temporal distribution change due to water temperature differences between the 2 yr. Part of the increased 1974 catch was also caused by larger catches of yearling alewives in May, June and July of 1974, compared to the same months of 1973. There appears to be a population change with the 1973 year class being larger than the 1972 year class. Seining data corroborate this conclusion, because YOY alewife catches were very high in 1973 compared to 1974, although no 1972 data were available for comparison. Juvenile alewives spend their first full year at mid-depths in the lake (Brown 1972), but with a large year class, we would expect increased inshore catches of this life stage. Reasons for decreased catches of the other four species, which caused the overall lower trawl catch in 1974, are difficult to ascertain, but some suppositions can be given. The approximately 300 fewer spottails caught in 1974 (total catch--2,948) does not appear to be a significant distribution or population change. However, the changes in catches of smelt, yellow perch and trout-perch are quite significant.

Smelt catch variation between 1973 and 1974 was the most significant in affecting the total trawl catch. Poor spawning success in 1974 was the major reason for decreased catches. Although we may have missed sampling during the spring spawning run (spawning peaks seldom last more than a week, Scott and Crossman 1973), low catches of YOY in 1974 indicate poor spawning success. Few adult smelt were caught by trawling because of net avoidance, but juveniles and YOY are susceptible. In 1974, fewer juveniles, approximately 1000 and 900 respectively, were caught in April and June than in 1973; and fewer YOY were caught during 1974 than 1973--approximately 5000

and 1000 respectively in August and September. Spawning success was probably not as good in 1973 as in 1972 because of the greater numbers of juveniles caught in 1973; however, this cannot be substantiated. Poor spawning in 1974 and possibly in 1973 may be related to warm water temperatures in March and April (see Fig. B6), but the exact cause is unknown. Whatever the reason, there was a definite smelt population decline during 1974 in the study area when compared to 1973.

Although the total yellow perch catch was greater in 1974 than in 1973 (see Tables B6 and B9), numbers caught by trawling were fewer in 1974. The cause for this decline is unknown. Possibly cooler water temperatures from June through October in 1974 compared to 1973 (see Fig. B6) were partially responsible for the decline.

Like the decline in yellow perch catches, the decline in trout-perch catches is difficult to explain. Trawl catches during August, September, October and especially June were lower in 1974 than in 1973. Again, cooler temperatures during summer and fall are suspected as the cause in changing distributions and therefore lowering catches. The exact reason why lower temperatures cause lower catches is not fully understood, but possibly different areas are utilized when lower temperatures occur in our area. Also, it may be that during the warmer temperatures in 1973, the fish utilized the study area to a greater degree than in more "normal" years. Another year of sampling may help to better define these changes.

In conclusion, trawl catches were quite variable between years. Both distributional variation and population changes of the five most abundant species contributed to trawl catch variation. Warmer water temperatures during 1973 are suspected of increasing the numbers of fish utilizing the study area compared to 1974. Decreased spawning success of alewives and smelt probably caused lower catches of YOY in late summer and fall of 1974.

While the trawling gear we use underestimates abundance of larger species and adults of some species (e.g., yellow perch and smelt), gill nets tend to catch larger species and adults of some smaller-size species. Therefore, gill net catches, in relation to the five most abundant species, are indicative of adult fish abundance.

Gill Nets --

In 1974, gill net catches (all species) increased from March to June, peaked in June and declined to December (Fig. B8). As water temperatures increased in spring, adult fish began their spring migration inshore. Peak June catch was caused by large numbers of alewives and spottails probably concentrating inshore to spawn. The July catch was also high, probably because of continued spawning by alewives, spottails and trout-perch. Numbers of adults declined sharply in August as most spawning activity had decreased considerably. This decline continued through December as most adults left the inshore water to overwinter offshore.

A comparison of gill net data between 1973 and 1974 (Fig. B8) indicates

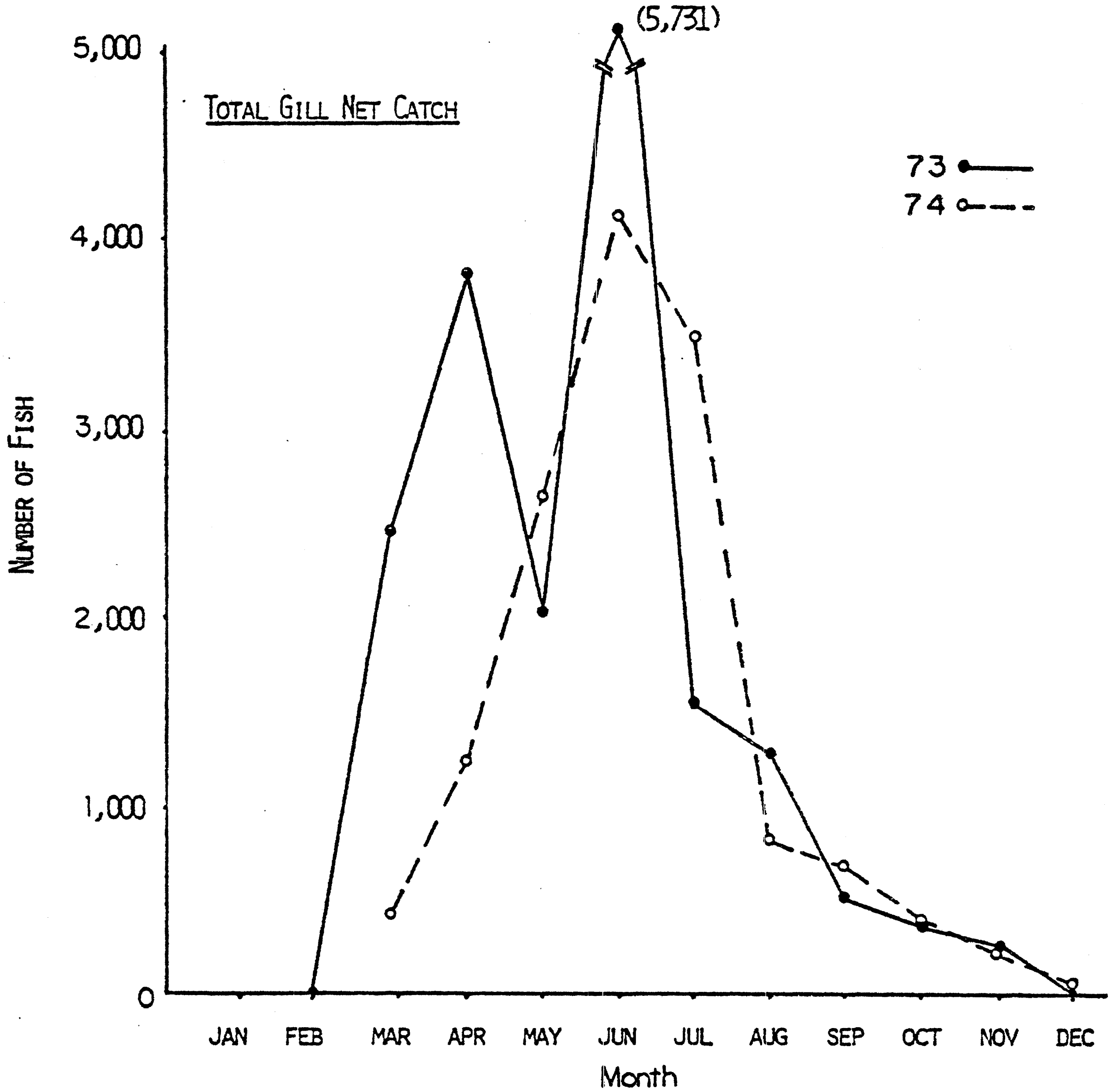


Fig. B8. Number of fish caught by standard series gill nets at Cook Plant study areas, southeastern Lake Michigan, 1973-1974.

catches were, like trawl catches, quite variable between some months, particularly in spring and summer. Warmer temperatures in March 1973 (compared to March 1974) evidently initiated the spring migration of alewives and spottails earlier in 1973. Although April temperatures were similar for the 2 yr, the spring migration apparently did not peak in 1974 until after we sampled in April. Whereas in 1973, gill net catches decreased in May from peak catches observed in April (as fish apparently dispersed into the increasing warm-water mass in May), in 1974 the spring migration peaked in May.

Although peak gill net catches occurred in June of both 1973 and 1974, total numbers caught were lower in 1974. While the spottail catch was higher by 433 fish, numbers of alewives and yellow perch caught were lower by 145 and 556 fish respectively. Reasons for these variations cannot be given. There may be a relationship with warmer temperatures observed in June 1973, but the exact causes are unknown. The June gill net catch disparity is another example of natural variation in the system; possibly caused by distribution changes of alewives and spottails while a local population decrease is suspected for yellow perch.

The July gill net catch was higher in 1974 than in 1973. Numbers of alewives caught in 1974 increased by approximately 2000, while numbers of spottails and trout-perch caught were only slightly higher. Increased alewife and spottail catches were probably due to spawning still taking place into July 1974, while it had started to decline in July 1973. The prolonged spawning activity occurring in June 1973 compared to June 1974 was clearly related to warmer water temperatures in 1973 (see Fig. B6). The yellow perch catch in July 1974 was lower than in 1973; causes for this decrease are unknown, but, as with the June decrease, a possible yellow perch population decrease may have occurred. Another factor which added to some of the July variation in perch catch between years was that an upwelling lowered water temperatures during day and night gillnetting in July 1974. Also in July 1973, an upwelling lowered temperatures at the 9-m Cook station during the night set.

In conclusion, gill net catches, like trawl catches, were quite variable between years. Catches from both gear types were lower in 1974 than in 1973. Undoubtedly distribution changes are causing the majority of the variation in alewife, spottail, smelt and trout-perch gill net catches. A possible population decline in yellow perch is suspected. Obviously natural variation in the system is quite high, with differences in water temperature probably contributing greatly to the changes.

Seines --

While trawling and gillnetting were carried out at the deeper stations, seining was only done at stations on the beach. Seine catches therefore, indicate fish abundance in a unique habitat compared to the other catches. Weather effects (e.g., storms) massively alter this habitat and make it quite changeable. The changeable nature of this habitat can drastically affect fish distributions causing considerable variation in catches.

Seine data for 1973 (see Jude et al. 1975) showed that alewives and spottails utilized the beach zone to a considerable extent, while smelt and yellow perch were there only during certain months. Trout-perch were rarely caught by seining. In the spring adult alewives and spottails concentrated in the beach zone as well as at deeper stations. Adult smelt also concentrated inshore during spring seeking spawning areas. During summer, spottails were abundant in the beach zone, while yellow perch were found there in June, possibly because of spawning activities. Starting in July, peaking in August and through October, YOY alewives and spottails utilized the beach zone as a nursery area.

Data for 1974 (Fig. B9) on total seine catch revealed a similar pattern of abundance as found in 1973. But some variation between the 2 yr occurred during spring and fall. During 1973, total numbers of fish increased sharply in May, peaked in August and declined into the fall. As discussed earlier, the spring alewife migration was delayed a month in 1974. Warm temperatures in March and April caused spring concentrations of fish to occur in April 1973 while more "normal" temperatures in 1974 caused the concentration to occur in May. Peak catch in August was lower in 1974 than in 1973, which was caused by lower catches of YOY alewives and spottails during August 1974. These two species showed a population decline in 1974 evidently related to lower spawning success. An upwelling during August 1974 seining may also have contributed to lower catches by colder water "forcing" fish from the area or dispersing individuals from schooling behavior. The very low seine catch in September 1973 was caused by high waves encountered when sampling. The September 1974 total seine catch was second highest for the year and revealed that YOY alewives and spottails were still using the beach zone as a nursery area. Undoubtedly the seine catch in September 1973 would have been higher if storm conditions had not been encountered because numerous YOY were collected in October 1973. This September catch difference between the 2 yr shows the natural variation common to the beach zone. Differences in catches during October of the 2 yr again point out the high spawning success of alewives and spottails which occurred in 1973 in the study area. As water temperatures declined in November, so did fish abundance, as migrations to deeper water were completed.

Some general overall conclusions can now be given on total standard series catches (all gear) which were discussed above. In 1974, alewives dominated the total catch comprising approximately 67%. They, along with spottails, smelt, yellow perch and trout-perch, made up 98.5% of the total catch. Numbers of fish caught monthly increased from a low in January to a spring peak in May. As water temperatures rose in spring, fish migrated from deeper water and concentrated inshore during May. Numbers dropped during June, but fish were still abundant inshore as adult alewives and spottails were inshore seeking spawning areas. Total numbers caught increased in July and peaked for the year in August as YOY alewives and spottails utilizing the inshore waters (especially the beach zone) for nursery areas were recruited to our gear. Numbers of fish collected

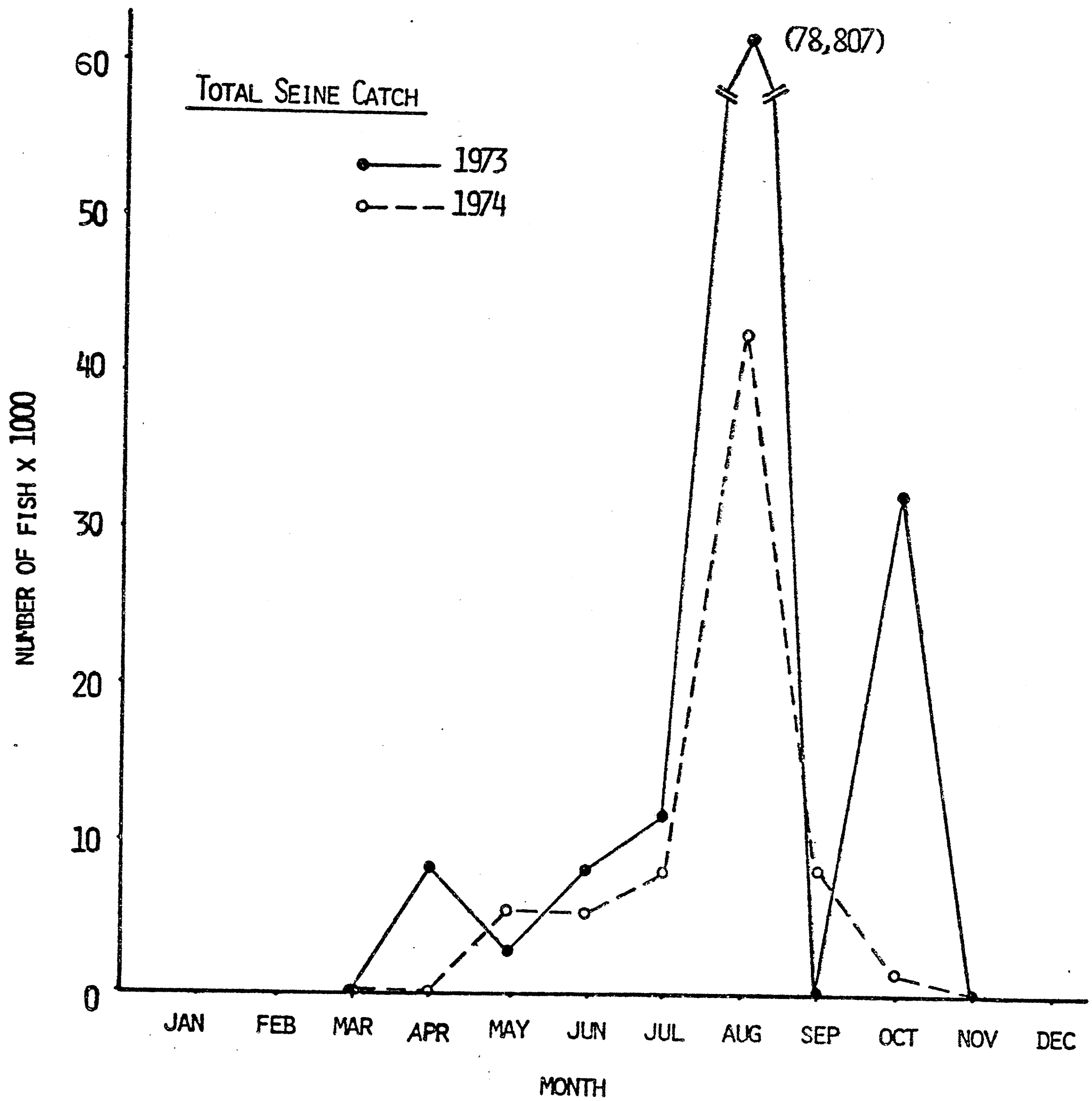


Fig. B9. Total number of fish caught with standard series seines at Cook Plant study areas, southeastern Lake Michigan, 1973-1974.

decreased each month during fall to winter as fish began migrating to deeper water with cooling temperatures.

A comparison of total catch between 1973 and 1974 showed a 41.3% decline in 1974. While catch differences were great for several of the less abundant species, most of the total catch decline was caused by lower catches of alewives and smelt, mainly YOY. Poor spawning success in 1974 compared to 1973 was believed responsible.

Comparisons of monthly distributions between 1973 and 1974 showed considerable variation. Temporal distribution and population changes contributed to these variations with distribution changes due to temperature differences causing the greatest variation. Considerable catch variation occurred in spring and fall. The spring migration of fish into the warming inshore waters occurred in April 1973, but did not occur until May 1974. Warmer water temperatures in March 1973 were probably the reason for the early 1973 spring migration. Fall variation in catch was caused by lower catches of YOY alewives and smelt in 1974.

Trawl and gill net catches between the 2 yr were quite variable, while seine catches showed less variation. Temporal distribution changes in the five most abundant species (especially alewives) caused most of the variation. Monthly temperature differences accounted for some of these changes. Local population declines are suspected for alewives, smelt and possibly spottail shiners and yellow perch.

Effects of Upwellings on Fish Distributions

Species associations and distributions of fish in the study area were found to be most influenced by five major factors: temperature, sexual activity, diel activity, schooling behavior and feeding habits. All of these factors are interrelated and the strength of their influence varies with time of year. These factors and some of their effects that have been determined will be discussed under individual species accounts.

Because water temperature had a very significant influence and to a varying extent regulates the other four factors, we have devoted a considerable discussion on its importance. We have divided temperature effects as they relate to fish in the study area into two categories - seasonal temperature changes and upwellings.

Seasonal temperature changes involve the warming and cooling of inshore waters. When temperatures reach certain values, spring migrations and spawning of several species in the study area are initiated. The time period when these values are attained change from year to year as climatic conditions vary and thus change temporal distributions monthly. Much of the variation in species distributions between 1973 and 1974 could be attributed to monthly temperature differences between the 2 yr and has been discussed. The following discussion will concentrate on our knowledge of upwelling effects.

While overall temperature changes affected temporal distributions dramatically, upwellings significantly affected spatial distributions. Upwellings are a frequent occurrence (approximately seven major upwellings per year occurred near the study area - see Figs. B4 and B5) in the southeastern inshore water and occur in summer and early fall (McLain 1969, Seibel and Ayers 1974). Upwellings occur in the study area when offshore winds push warm eplimnion waters offshore; the thermocline rises and cooler hypolimnion waters move inshore. Intensity of upwellings can vary with time and wind direction. We have recorded upwellings affecting the deeper stations (water temperature was 11.3 C at 9 m, while at 6-m stations temperatures were significantly higher 19.9 C). On another occasion an upwelling affected temperatures at the beach zone (12.0 C, average temperature for this month in the beach zone is approximately 20 C). Spatial extent of upwellings can also vary considerably. Depending on wind direction, an upwelling can affect the Cook Plant area while not affecting the Warren Dunes area and vice versa. As a consequence of temperature changes due to an upwelling, fish distributions are significantly affected.

Determining the effect of upwellings on individual species movements was very difficult. The complexity and variation of each upwelling caused different distributions of individual species. Distributions of some species were not the same for each upwelling. The time of sampling also complicates the analysis of fish movements. We may have sampled when an upwelling was just beginning, in its full extent, or at its ending. All of the above factors confound the effect an upwelling has on fish movements.

These effects vary depending on fish species and age-size class. In general, we can separate most species caught in the study areas into warm-water and cold-water species. These two categories are quite broad with no one temperature separating them. Although a species may generally prefer a certain temperature range, preferences can change with age or time of year or because of behavior responses (e.g., spawning). Fish caught in modest to abundant numbers in the study area that can be classified as warm-water species are: alewife, spottail shiner, yellow perch, trout-perch, white and longnose sucker, johnny darter, emerald shiner, longnose dace, northern pike, carp, gizzard shad, ninespine stickleback and bluegill. Cold-water species are: smelt; lake, brown, and rainbow trout; coregonids; slimy sculpin; and coho and chinook salmon. Again, it must be emphasized that the two groups do overlap and some species e.g., johnny darter, trout-perch, and longnose sucker are probably in the mid-range between the two groups. Also, a species may be classified in one group, but at times we catch it in all temperature ranges. For example, rainbow trout is a cold-water species, but we have regularly caught juveniles by beach seining when water temperatures were 25 C.

When an intense upwelling occurs in the study area, warm-water species generally leave the area or disperse, while cold-water species enter the area. These patterns do not hold for all species listed in the preceding paragraph, but several species do show these movements.

Some interesting and informative observations on fish responses to a change in the thermocline (due to an internal seiche) in August were made by Emery (1970) in Georgian Bay, Lake Huron. Although an internal seiche is a very abrupt occurrence, the physical changes are probably similar to those in an upwelling. Emery observed (via SCUBA diving) that most white suckers, smelt, yellow perch and ninespine sticklebacks moved shoreward as the cold water moved into the area, while whitefish and alewife moved upward into the warmer surface water. Although johnny darters were present before the seiche, they were not seen during or after. Trout-perch appeared to be unaffected and stayed in the area occupied by the cold-water mass. Mottled sculpins also stayed in the cold water but feeding ceased and swimming became erratic; some sculpins died. These differing responses and movements are indicative of the complexities in natural temperature induced changes.

During 1973 and 1974 several upwellings occurred in our study area when sampling was proceeding. The movements of smelt and bloaters were easily followed. Some patterns in the movements of other cold-water species, e.g., coho and chinook salmon, brown and lake trout, and lake whitefish were also established during upwellings. Movements of warm-water species did not follow set patterns during each upwelling. Apparently these movements are quite complex and may vary with each upwelling's intensity, configuration, and month of occurrence.

Because upwellings occurred while sampling in July and August during both years, upwelling - no upwelling comparisons could not be made between the same months of both years. If during one month, e.g. July 1973 an upwelling had occurred but none occurred in 1974, a comparison of fish distributions between months could have been analyzed using July 1974 as a control month. Comparisons between years were also difficult because population numbers may vary and overall weather conditions during one year may deviate considerably from the norm and thereby affect distributions. Of the three types of fishing gear, only catches from trawls could be accurately analyzed for upwelling effects. Trawl hauls are short in duration and performed at two depths and two areas. Four monthly samplings yielded valuable information on upwelling and thermocline effects. Trawls were performed when an upwelling directly affected only the deeper stations (June 1973, August 1974); on another sampling series (September) an upwelling occurred in 1973 and not in 1974. On 19 June 1973 a series of day trawls were performed at six depths (6 to 21 m) off the Cook Plant when the thermocline was between 9 and 12 m. These four collection series yielded insights into distribution changes caused by upwellings and position of the thermocline. Gill net catches did not yield directly useful information on distribution patterns, although some information on the presence of larger fish during upwellings was discerned. Because gill nets are set for approximately 12 hr, a net could be fishing in warm water, then in cold water as an upwelling forms. The catches therefore may be a combination of fish present in the warm water and fish which moved in with the upwelling. Only during August 1974 did an upwelling occur in the beach zone while seining and therefore directly affect catches. These catches and the four

sets of trawl catches will be discussed below.

During warmer months of the year - June, July, August and September, smelt and bloaters reside in deeper colder waters of the lake. Our data indicate they enter the inshore waters during these months only when water temperatures drop below approximately 18 C (low numbers of YOY smelt are sometimes caught when temperatures are above 18 C). These events occurred when overall monthly temperatures were low or when upwellings transpired. Trawl catches during periods when upwellings had dropped temperatures at only one or two of the four stations revealed this movement (Fig. B10). In June 1973 and August (night) 1974 the thermocline was at or near the deeper (9 m) stations, but temperatures were still high at 6-m stations. At the deeper stations catches of smelt were very high while at the shallow stations catches were very low to zero. Bloaters were only caught at the deeper stations. During the August day trawling series the thermocline was at 9-m station H (Warren Dunes) but did not directly affect the Cook Plant stations (C and D). Smelt and bloaters were only caught at station H (except one smelt caught at 6-m station C).

Smelt and bloaters (especially juveniles of both species) must stay almost exclusively within the thermocline or possibly hypolimnion waters during summer when inshore temperatures are somewhat above 18 C. When an upwelling occurs these fish follow the thermocline inshore. This inshore temperature-related movement can probably occur in less than 24 hr because water temperature declines due to upwellings have been recorded in this time period (see Figs. B4 and B5). Wells (1968) has indicated that appreciable movement of fish in response to temperature changes may occur in a few hours and major redistributions may take place in 2 or 3 days in southeastern Lake Michigan. These sudden temperature changes cause complex distributions of species in the study area, further complicating interpretations of summer catch data.

While smelt and bloaters exhibit a definite inshore movement with the thermocline, movements and distributions of other species during upwellings are less understood. During September of 1973 an upwelling was in progress during trawling, while in September 1974 no upwelling occurred while trawling (Table B13). Although monthly comparisons between years are difficult to interpret because of population changes and overall weather variation, some patterns due to the upwellings are obvious between September catches of the 2 yr.

Day catches (Table B13) during the September upwelling (1973) contained more species of fish and greater numbers of fish of a given species. Evidently these species, besides smelt, concentrated inshore, possibly seeking warmer water. This concentration also indicates that at least some fish did not follow the warm water out of the study area as cold water entered. Emery (1970) observed trout-perch remaining in the cold water as the thermocline moved inshore during an internal seiche in Georgian Bay, Lake Huron. The distance involved with following the warm-water mass in Lake Michigan is probably the reason for the fish staying inshore. With

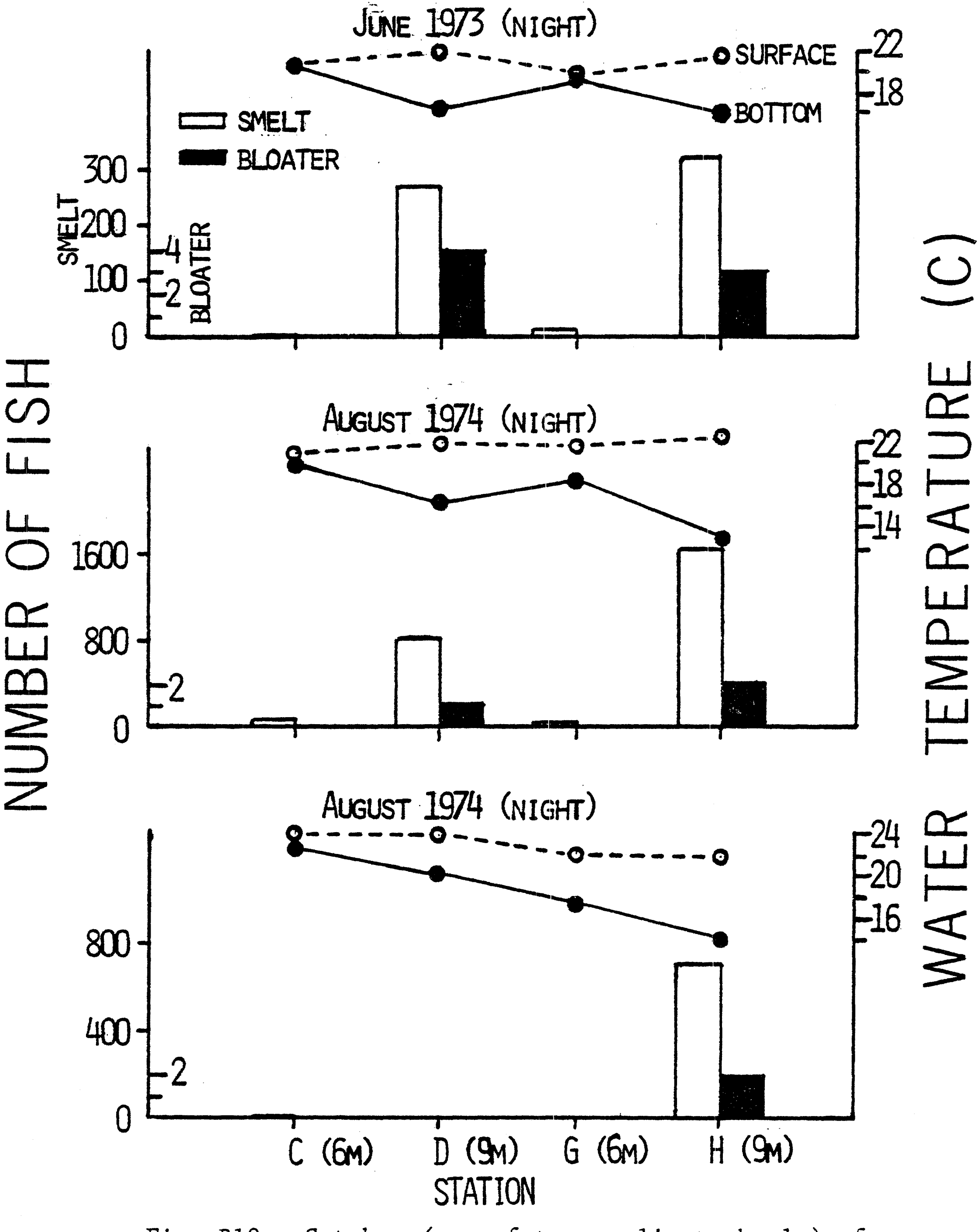


Fig. B10. Catches (sum of two replicate hauls) of smelt and bloaters from three series of trawl samples collected in June 1973 and August 1974 when upwellings caused low temperatures at the deeper stations of the Cook Plant study areas, southeastern Lake Michigan.

Table B13. Number of fish (includes the sum of two replicate hauls) in September trawl catches from Cook Plant study areas in 1973 when an upwelling occurred and 1974 (no upwelling). S = surface, B = bottom.

September Day Trawl Catch

Station

Species		Cook-6m		Cook-9m		Dunes-6m		Dunes-9m	
		1973	1974	1973	1974	1973	1974	1973	1974
Alewife		463	86	92	1	67		53	27
Spottail		17		28		25		42	
Smelt		232		393	3	133	2	440	1
Yellow perch		6	3	34	41	21		47	
Trout-perch		2		41		2		22	
White sucker		2							
Carp									1
Slimy sculpin								1	
Water temp. (C)	S:	13.0	19.7	12.5	19.5	11.5	19.2	12.2	19.5
	B:	12.0	19.0	9.0	18.0	11.0	17.6	10.0	17.5

September Night Trawl Catch

Station

Species		Cook-6m		Cook -9m		Dunes-6m		Dunes-9m	
		1973	1974	1973	1974	1973	1974	1973	1974
Alewife		3	29		6		6	3	11
Spottail		339	8	10	7	194	52	73	19
Smelt		72	11	133	25	16	16	8	31
Yellow perch		25	14	34	6	10	1	36	19
Trout-perch		37	26	19	9	18	25	24	28
Johnny darter		6	1	3	3			2	3
White Sucker		1	1						1
Slimy sculpin						2		2	2
Water temp. (C)	S:	14.3	19.0	14.7	19.2	14.1	19.5	14.5	19.0
	B:	14.1	17.5	14.4	17.2	14.5	17.5	14.8	16.8

strong easterly winds blowing for several days, a strong upwelling will occur and warm water can be moved several kilometers out into the lake.

September night catches (Table B13) indicated a similar concentration of spottails, smelt and yellow perch inshore during the upwelling. Fewer alewives and smelt were caught at night than during the day catches. These fish moved out of the trawling zones at night during the upwelling for unknown reasons. Catches at night during 1974 (no upwelling) show generally more fish and more species than day catches. Evidently at night fish move into the trawling zone after being elsewhere during the day. This nighttime increased concentration did not occur during the upwelling in 1973. Apparently the fish, except smelt and alewives, were more evenly distributed during day and night in the colder water.

Johnny darter, white sucker and slimy sculpin night catches were similar between the 2 yr (Table B13). Distributions of these fish at night were apparently not changed by the September 1973 upwelling. Evidently these species are quite localized in habit and do not migrate extensively with abrupt changes in water temperature.

Another trawl series which yielded considerable information on thermocline effects occurred on 19 June 1973. Six depths from 6 to 21 m were trawled during the day (Table B14). During this series the thermocline was between the 9- and 12-m depths. Catches of some of the species showed definite distribution patterns due to the thermocline.

Three species (alewife, spottail and yellow perch) were more concentrated in warmer water, inshore from the thermocline (Table B14). Spottails were only caught inshore demonstrating their preference for shallow and warm water. Although concentrated inshore, alewives and yellow perch were caught in low numbers in deeper, colder water. These two species showed preference for warmer water, but also probably preferred greater depths than spottails. Part of the reason for these two species concentrating inshore may be due to spawning behavior, because both spawn during June in or near the study area.

Catches of smelt, trout-perch and bloaters (XC) were greatest around the thermocline and then decreased as depth increased. Again the preference of smelt and bloaters for thermocline waters was demonstrated. Although trout-perch were concentrated near the thermocline, high catches in deeper colder water indicated the fish probably prefer these waters. Trout-perch distributions were affected considerably by upwellings when the fish were concentrated inshore during spawning periods (see Trout-perch section for further discussion) contrary to results found by Emery (1970) for trout-perch in Georgian Bay, Lake Huron.

Catches of slimy sculpins occurred only in cold water during the June 19 trawl series (Table B14) which demonstrated the preference this species has for cold water. Rottiers (1965), Wells (1968) and Jude et al. (1975) also found slimy sculpins in Lake Michigan preferred cold water.

Table B14. Day trawl catches (includes the sums of two replicates) collected during 19 June 1973 from six depths off the Cook Plant, southeastern Lake Michigan.

Station	Depth (m)	Bottom temp. (C)	AL[1]	SP	SM	YP	TP	JD	LT	SS	CC	XC
C	6	21.0	72	24		139	1					
D	9	18.5	205	12	72	25	123	5			1	4
4	12	8.6			51	4	44			4		2
5	15	7.2	1		16	6	4		1	3		1
6	18	9.0	18		4	4	15			2		
E	21	7.2	2		7	7	3			12		

[1] See Table B5 for definitions of species abbreviations.

The complexities of the upwelling phenomenon create quite variable data. Some of this complexity can be seen in the August seine data for the 2 yr when an upwelling occurred at beach stations during 1974 (Table B15). Day catches of alewives and spottails revealed no definite distribution pattern among the three seining stations because of the upwelling when compared with similar distribution during 1973 (no upwelling). In 1974 catches at beach stations A and F were lower during the upwelling, but at B the opposite occurred, probably as a result of contagious distributions (i.e., schooling behavior).

Day catches of smelt and bloaters occurred only at beach stations during the August upwelling (Table B15). Their shoreward movement with the thermocline was, like trawl data demonstrated, confirmed by seine data. August 1974 (upwelling) was the only time bloaters were ever caught by seining during June, July, August and September of the 2 yr.

Considerably more yellow perch were caught during 1974 by day seining during the August upwelling than were observed in August 1973 seine catches (Table B15). Apparently this species concentrated in the beach zone when water temperatures were cold, but not when temperatures were high. Emerald shiners were only caught by day seining when the temperatures were high. This species moved out of the beach zone when the upwelling occurred.

Table B15. Number of fish (includes the sum of two replicate hauls) in August seine catches from Cook Plant study areas in 1973 (no upwelling) and 1974 when an upwelling occurred.

August Day Seine Catch

Species	A-N Cook 1973	A-N Cook 1974	B-S Cook 1973	B-S Cook 1974	F-Dunes 1973	F-Dunes 1974
Alewife	19599	8628	9669	27059	47775	215
Spottail	259	18	127	3468	1302	95
Smelt		2				1
Yellow perch	1	12		502		5
Longnose sucker				1		
Emerald shiner	1		5		1	
Carp				1		
Northern pike				1		
Bloaters				2		
Golden shiner		1				
Bottom temp. (C)	26.0	13.0	27.0	12.0	26.8	12.5

August Night Seine Catch

Species	A-N Cook 1973	A-N Cook 1974	B-S Cook 1973	B-S Cook 1974	F-Dunes 1973	F-Dunes 1974
Alewife	8	120	1	43	5	122
Spottail		1260	6	506	15	528
Smelt		1		5		1
Yellow perch		63		214		5
Trout-perch		3	3		1	
White sucker				1		
Rainbow trout			11			
Emerald shiner			4			
Longnose dace			4	1		
Carp				1	1	
Brown trout			2			
Channel catfish					2	
Bluegill					1	
Bottom temp. (C)	24.5	17.7	23.8	14.3	24.5	16.9

Like the day trawl data, day seine data showed more species caught during the upwelling when compared to similar periods of no upwelling. This again was probably due to species that concentrated inshore seeking warmer water during the upwelling. But it may be that the very warm day temperatures during 1973 prevented species with lower thermal preferences from inhabiting the beach zone.

During the August 1974 upwelling, night seine catches revealed more definite patterns in distributions than day catches (Table B15). Night catches of alewives and spottails were greater during the upwelling than comparable periods in 1973. These two species left the beach zone at night in 1973 (no upwelling), but in 1974 both species were still in the beach zone during the upwelling, although alewives were caught in lower numbers at night. Smelt and yellow perch were not caught at night in 1973, but appeared in night seine catches during the 1974 upwelling.

Interestingly, two cold-water species, rainbow and brown trout, were not seined during the August upwelling 1974, but in 1973 they were caught at beach station B in very warm water. The cause for this catch during warm water temperatures was unknown, although young of these species were commonly collected at beach stations during the summer.

Gill net catches during upwellings suggested that several species of cold-water fish follow the thermocline inshore. During June, July, August and September of 1973 and 1974 larger individuals of lake and brown trout, chinook and coho salmon were usually caught during upwellings. Coho salmon were at times caught when no upwelling was directly affecting the stations, but overall monthly temperatures were 18 C or lower. Temperature-catch relationships of these species were not as distinct as the ones for smelt and bloaters. Also, when an upwelling did occur these species were not always caught. Low numbers caught and length of time gill nets were set prevents establishment of a clear relationship for these species, but a general suggestion could be made.

Two lake whitefish were caught during warmer months in 1973 and 1974. Both fish were caught when upwellings had lowered inshore temperatures. Again, these data suggested that lake whitefish also follow the thermocline inshore during upwellings.

In conclusion, upwellings occur frequently in the study area during June, July, August and September. The extent and intensity of upwellings vary considerably causing complex temperature regimes. All these factors contribute to significant changes in fish distributions during warm months when inshore movements of the thermocline occur. We have found definite patterns in movements of cold-water species (especially smelt and bloaters) with the thermocline during upwellings. Movements and distributions of warm-water species are less understood presumably because of the complexities in upwelling formations and different behavior responses with each species, depending on age and size. These movements and distributions can drastically vary the composition of fish catches and thereby cause

considerable difficulties in our data interpretation. We are just beginning to fully understand what the forces are and how they cause changes in spatial and temporal fish distribution.

These findings do reveal that fish populations inshore are subjected to natural changes in water temperature. The frequency of major upwellings (approximately seven per year) indicates that they are not abnormal events, but have been occurring over the years on the southeastern shore of Lake Michigan. Consequently, fish populations that are present in the study area have adapted to these changes. Upwellings serve as an important mechanism in extending the spatial range of many species. Because of thermal preferences many species would be restricted to deep colder offshore waters during the summer; however, upwellings increase the range of these fish into inshore areas. In effect there is no distinct boundary for fish separating offshore from inshore waters in southeastern Lake Michigan.

Most Abundant Species

Alewife --

Although it was not native to Lake Michigan, the alewife has had a considerable impact on the ecology of Lake Michigan. After first entering from Lake Huron in the late 40's, it had spread to the southern end of Lake Michigan by 1952 (Miller 1957). Its population reached an apparent peak in the mid 60's after which a massive die off occurred in 1967. Today the alewife is numerically the most abundant fish in Lake Michigan. As a result of its great abundance and seasonal presence in all areas and depths of the lake, the planktivorous alewife has been implicated in population declines of several fish species (Smith 1968b, 1970) and several zooplankton species (Wells 1970). We found the alewife to be very abundant seasonally in the inshore study areas of southeastern Lake Michigan during 1973 and 1974. The following is a brief summary of 1973 findings.

Alewives constituted 76% of the total standard series catch in 1973. Seines collected the most alewives (84% of total catch) and most of these fish were YOY caught in late summer and fall. Gill nets and trawls each caught approximately 8% of the total alewife catch.

Inshore abundance of two age-size classes (YOY and adults) of alewives varied seasonally. Adults first appeared in low numbers during March, then peaked in abundance in April. Numbers again increased in June when most spawning occurred. Vertical migrations, nocturnal surface activity and schooling of adults contributed to variability in the data. By August most adults had migrated to deeper water. YOY first became available to stadard series seining gear in July and reached high abundance in late summer and early fall. Plankton nets collected alewife larvae mostly in June and July. YOY concentrated in the beach zone during the day and entered deeper water at night. By November most YOY had migrated to deeper water.

The preceding was a very brief summary of 1973 findings; a more detailed discussion occurs in the 1973 report (Jude et al. 1975). Following

is a discussion of 1974 data and comparisons with 1973 data.

Statistical analysis --

Trawls -- The trawl ANOVA for 1973-1974 combined (Table B16) yielded three highly significant ($p<.001$) main effects (MONTH, DEPTH, TIME) and 12 significant interactions. Main effects were confounded by five first-order interactions (MxT, MxA, AxT, YxM, YxA), four second-order interactions (MxAxD, MxAxT, YxMxT, YxMxA) and three third-order interactions (MxAxDxT, YxMxAxT, YxMxDxT). By comparison there were four main effects in 1973 (MONTH, DEPTH, TIME, AREA) and six interactions (MxA, AxT, MxT, DxT, MxAxT, MxDxT), one of which dropped out of the combined 1973-1974 ANOVA (DxT). Appearance of third-order interactions in the combined ANOVA and an increase over 1973 in total number of interactions indicated the added complexity of the combined 1973-1974 data. Second- and third-order interactions proved difficult or impossible to analyze in detail. Biological and physical events contributing to significant main effects and interactions are discussed below.

Interestingly, AREA was no longer a significant main effect as it was in 1973. In 1973 alewife mean trawl catches were greater at Warren Dunes than at Cook, except in September (Fig. B11), giving rise to the AREA effect. During 1974 the trend was reversed and larger alewife catches prevailed at Cook during much of the year causing disappearance of AREA as a main effect in the combined 1973-1974 ANOVA.

Another major source of variance, involving YEAR, AREA, TIME and MONTH was evident in August and was probably due to a large 1973 night trawl catch at Warren Dunes 6- and 9-m stations (Fig. B12). This catch consisted mostly of YOY (Jude et al. 1975, Fig. B10) which typically were seined in large numbers during the day and were not usually as numerous in either night trawls or night seines. Diel movement of alewife YOY has not been well studied, but scarcity of alewife YOY in our night seines and trawls (which fish the bottom of the lake) suggests that this life stage generally moves away from shore and upward in the water column at night. However, in August 1973 an upwelling occurred, affecting 6- and 9-m stations (Table B1, Jude et al. 1975), and may have caused alewife YOY to remain in the warmer inshore waters at Warren Dunes (14.9 C at 6 m and 15.8 C at 9 m). Cook 6- and 9-m stations were fished the preceding night and were not as warm (12.2 C at 6 m, 8.5 C at 9 m) which may explain why YOY were not trawled at Cook stations during the upwelling. Alewife YOY are believed to prefer warm water and would be expected to avoid colder upwelled water (see Temperature -catch relationships). August 1973 night seine catches could not be compared with 6- and 9-m catches during the upwelling since seining was conducted more than a week beforehand. During the rest of 1973 and 1974, alewife trawl catches were routinely low.

Numbers of alewives trawled at Cook and Warren Dunes varied considerably both within and between years (Fig. B12). While AREA was not a significant main effect in the combined 1973-1974 ANOVA, alewives were often observed concentrated at one or the other of the two areas studied (Cook and Warren Dunes) at other times than those discussed above. Undoubtedly this

Table B16. Summary of analysis of variance for alewives caught in trawls at Cook Plant study areas from April through October 1973 and 1974.

Source of variation	df	Adjusted mean square[1]	F-statistic
YEAR	1	.66510	3.42
MONTH	6	5.71775	29.38**
AREA	1	.09122	.47
DEPTH	1	3.21665	16.53**
TIME of day	1	3.15147	16.19**
YxM	6	2.47115	12.70**
YxA	1	6.26959	32.22**
MxA	6	1.18288	6.08**
YxD	1	.04371	.22
MxD	6	.25091	1.29
AxD	1	.20908	1.07
YxT	1	.13377	.69
MxT	6	5.37989	27.64**
AxT	1	5.00030	25.69**
DxT	1	.65702	3.38
YxMxA	6	.90033	4.63**
YxMxD	6	.14696	.76
YxAxD	1	.09056	.47
MxAxD	6	1.02977	5.29**
YxMxT	6	2.47434	12.71**
YxAxT	1	.17872	.92
MxAxT	6	.75751	3.89*
YxDxT	1	.54914	2.82
MxDxT	6	.42938	2.21
AxDxT	1	.65224	3.35
YxMxAxD	6	.24157	1.24
YxMxAxT	6	1.11722	5.74**
YxMxDxT	6	.70451	3.62*
YxAxDxT	1	.12568	.65
MxAxDxT	6	.66561	3.42*
YxMxAxDxT	6	.18939	.97
Within cell error	110[2]	.19462	

** Significant ($P < .001$).
 * Significant ($P < .01$).

1 Mean squares were multiplied by harmonic cell size/maximum cell size ($n_h/N = .9825$) to correct for 2 missing observations where the cell mean was substituted.

2 Two degrees of freedom were subtracted to correct for 2 missing observations where the cell mean was substituted.

variation accounted for parts of the interactions involving AREA and also was related to TIME and DEPTH effects. The species schools extensively (Emery 1973, Graham 1957, Wells 1968 and our observations), the substrates are similar in both areas, and regular preference for a particular area was not exhibited. It is expected that AREA data reflect aggregation and alongshore movement of alewives in response to physical factors such as upwelling, current and weather, as well as biological factors like schooling, predator avoidance, feeding and spawning.

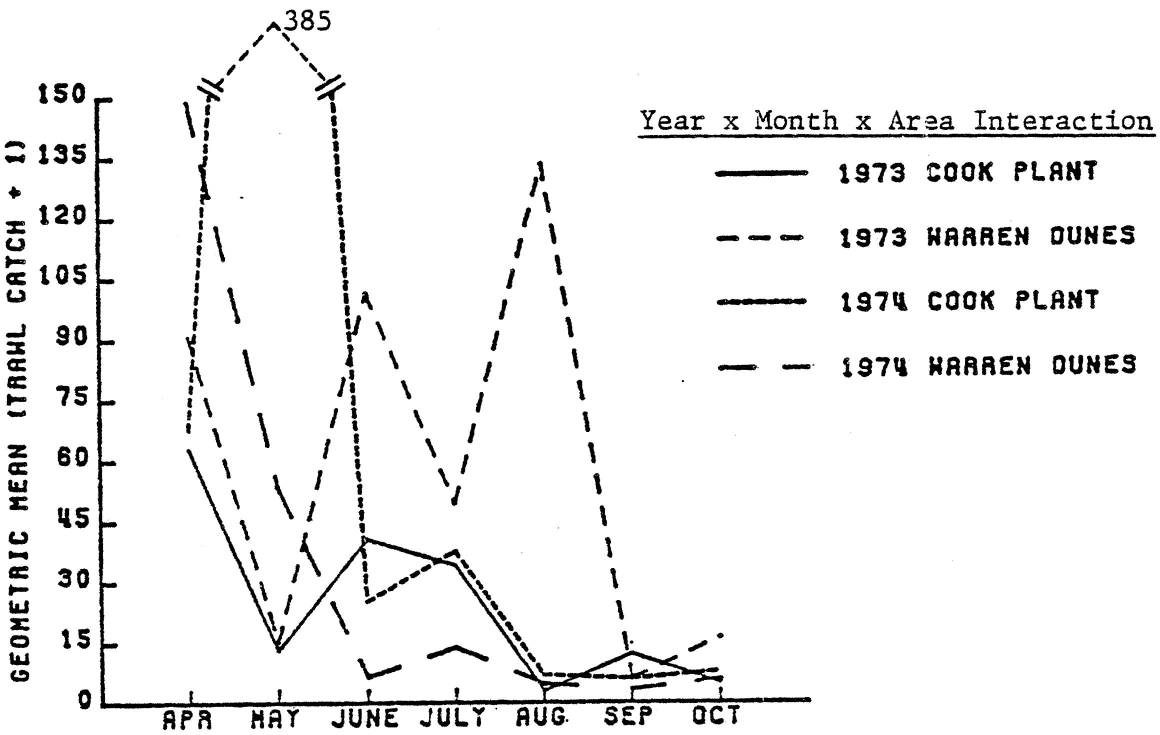


Fig. B11. Geometric mean number of alewives caught in duplicate standard series trawls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

Biological explanation of diel behavior (TIME effects) was difficult. In both years the total number of day-caught alewives surpassed numbers caught at night, but the extent of monthly variability in diel distribution was great (Fig. B12). Night catches were larger in May 1973 (Cook and Warren Dunes) and in July 1973 (Cook), while in 1974 night catches were larger in May and June (Warren Dunes only) and in October (Cook). A definite pattern was not evident.

Literature on alewife diel activity is ambivalent. Scott and Crossman (1973) stated that alewives moved inshore at night. Emery made SCUBA observations in Georgian Bay indicating that apparent nightly inshore

Year x Month x Area x Time Interaction

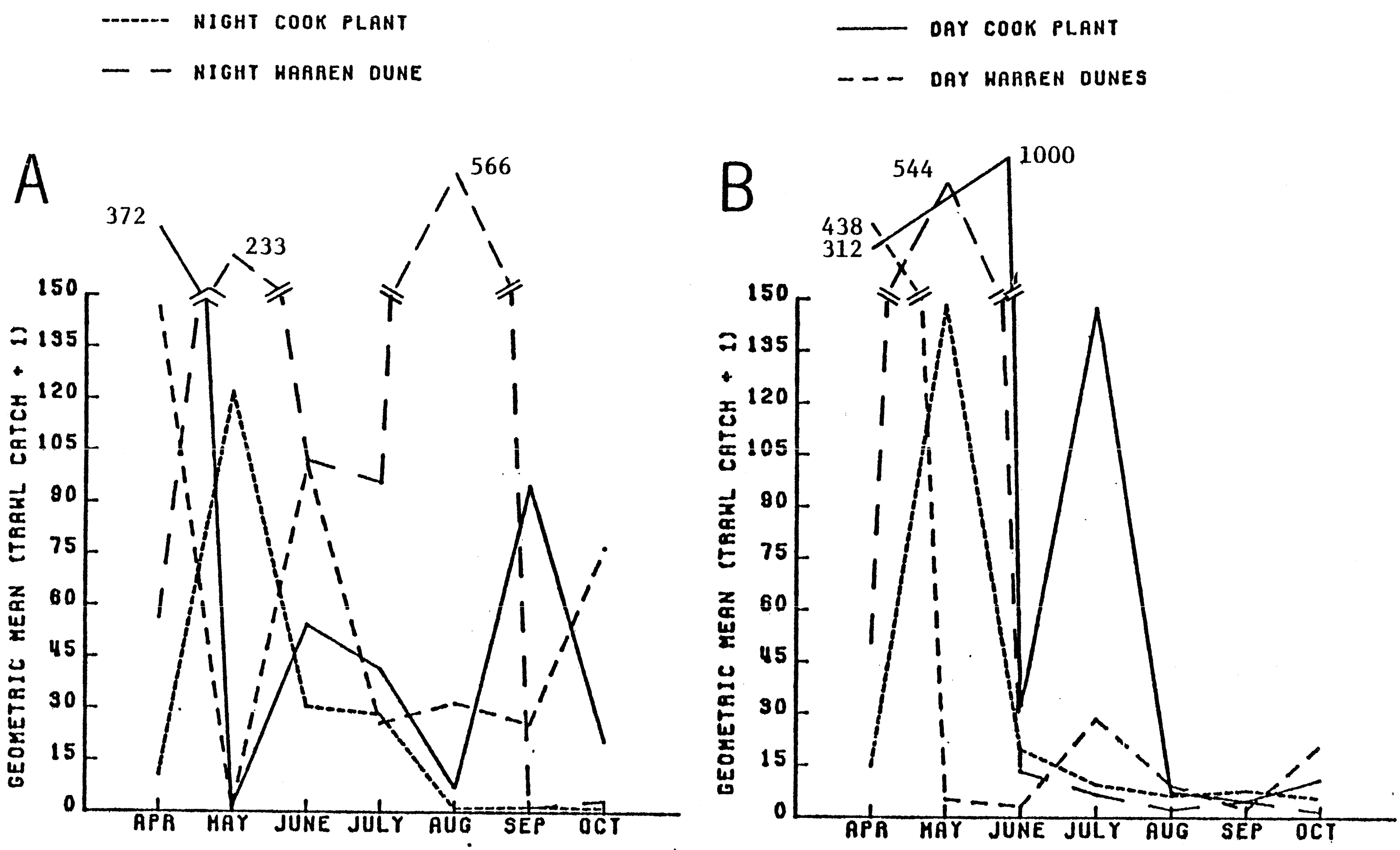


Fig. B12. Geometric mean number of alewives caught in duplicate standard series trawl hauls during 1973 (A) and 1974 (B) at Cook Plant study areas, southeastern Lake Michigan.

movement was really due to migration of alewives toward the surface at night. Richkus (1974) reported morning and evening activity peaks and occasional large nocturnal migrations of alewives in a Rhode Island river. He also noted that alewives may change depth to avoid light. Daytime activity peaks and light avoidance were also seen by Saila et al. (1972) in the same river system. Graham (1956) stated that adults and juveniles moved to shallow water (depth not indicated) during dusk and at night from April through late July in Lake Ontario. In daytime adults were in offshore surface waters while juveniles remained near the bottom of the lake in 1.8-3 m of water.

On several occasions we observed alewives concentrated near the surface at night and we believe that nocturnal upward migration occurs in the study area. Since our trawl fishes on the lake bottom, such populations would be somewhat out of trawling range at night. The situation is further complicated by the undulating vertical movement displayed by alewife schools (Graham 1957), an activity which could carry the species in and out of trawling range.

Catch data correlated with depth produced similarly variable results (Fig. B13). Trawling in 1973 yielded more alewives at 6 m as mentioned above, but in 1974 the trend was reversed, due particularly to large catches at 9 m (Warren Dunes) in April and May. Diel vertical migration and vertical movement of alewife schools probably contributed to the observed effects of DEPTH as well as of TIME in the ANOVA. More meaningful inferences about alewife depth distribution came from comparison of beach catches with catches at deeper stations than from comparison of 6- and 9-m catches alone (see <u>Seasonal distribution by age-size class</u>).

In summary, despite considerable variability in the data, seasonal patterns in both years were generally the same (Fig. B14). Adults moved inshore in spring (April 1973, May 1974), then moved offshore as the rest of the lake warmed (May 1973, June 1974). A second peak of inshore movement occurred in summer (June 1973, July 1974) as adults returned to spawn. Trawl catches declined from August onward and generally did not reflect the large number of YOY present during midsummer and early fall. YOY were taken mainly in seines. The decrease in numbers of alewives trawled in fall appeared to agree with the observations of Reigle (1969) who noted that alewives were offshore, mostly at 27-37 m during September and October in southern Lake Michigan. In another fish study in the southern part of the lake, Wells (1968) reported that alewives were concentrated at 27-46 m in October. However, preliminary impingement data from the Cook Plant during 1975-1976 indicated that some alewives may remain in the study area during fall and early winter. These observations will be analyzed in more detail in subsequent reports.

YEAR was not a significant main effect in spite of a 49% decline in numbers of alewives caught in standard series gear from 1973 to 1974. Most of the decrease was attributable to reduced 1974 seine catches; more alewives were in fact trawled in 1974 (16,173) than in 1973 (12,178).

Year x Month x Depth x Time Interaction

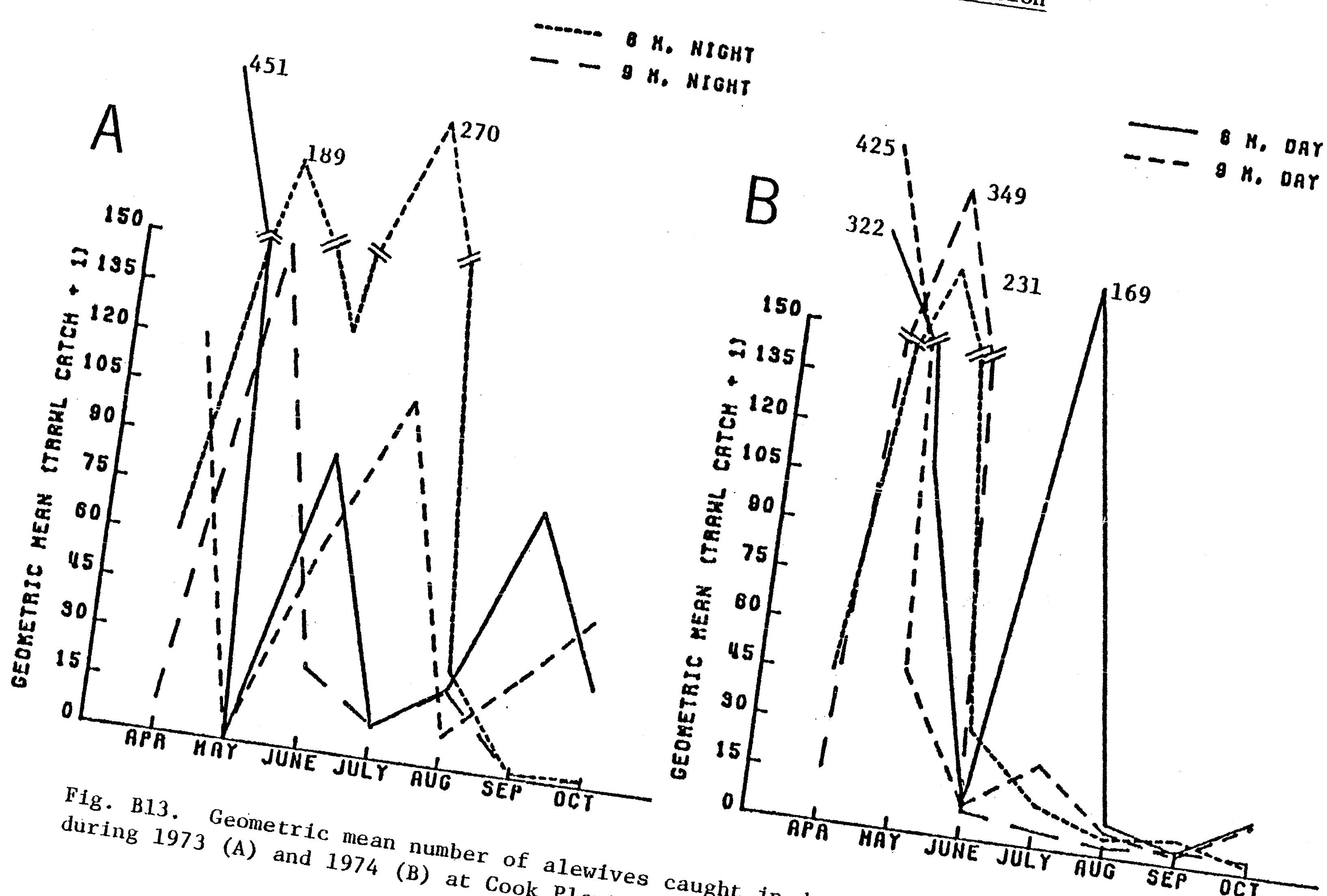


Fig. B13. Geometric mean number of alewives caught in duplicate standard series trawl hauls during 1973 (A) and 1974 (B) at Cook Plant study areas, southeastern Lake Michigan.

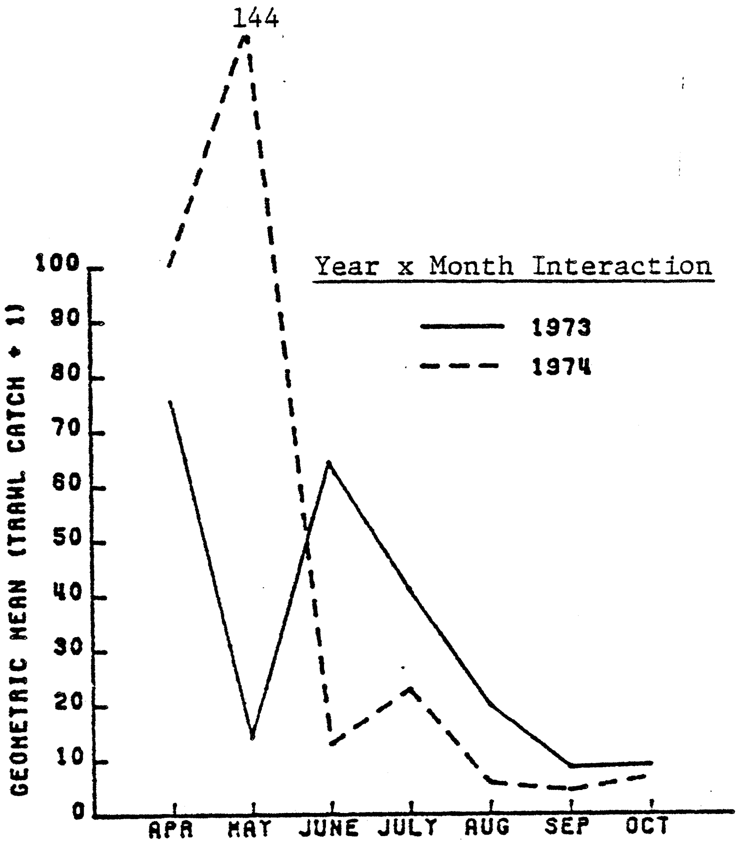


Fig. B14. Geometric mean number of alewives caught in duplicate standard series trawls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

All ANOVA factors (MONTH, DEPTH, TIME, AREA, YEAR) appeared in significant interactions. As an index of relative importance of each factor, MONTH occurred most frequently (10 times), followed by AREA (8), TIME (7), YEAR (6) and DEPTH (3).

There were several phenomena we believe contributed importantly to significant trawl catch interactions. In 1974 peak numbers of alewives occurred inshore later in the spring (May) than in 1973 (April), possibly as a result of colder water temperatures early (March) in 1974 (Figs. B14 and B15). Cooper (1961) noted that alewife inshore migration in Rhode Island was closely associated with water temperature. The spring alewife maximum catch was larger in our study area during 1974. We attributed portions of significant interactions involving YEAR and MONTH to these events, which were also partially responsible for significant interactions involving the other factors, AREA, DEPTH and TIME of day. The May 1974 spring peak in alewife numbers occurred mainly at the 9-m Warren Dunes station at night, while during the day it appeared at the Cook 6-m station. In 1973 the spring alewife maximum (in April) also appeared at the Cook 6-m station during daytime, but there was no pronounced night peak at any depth, unlike 1974 (Figs. B12 and B15).

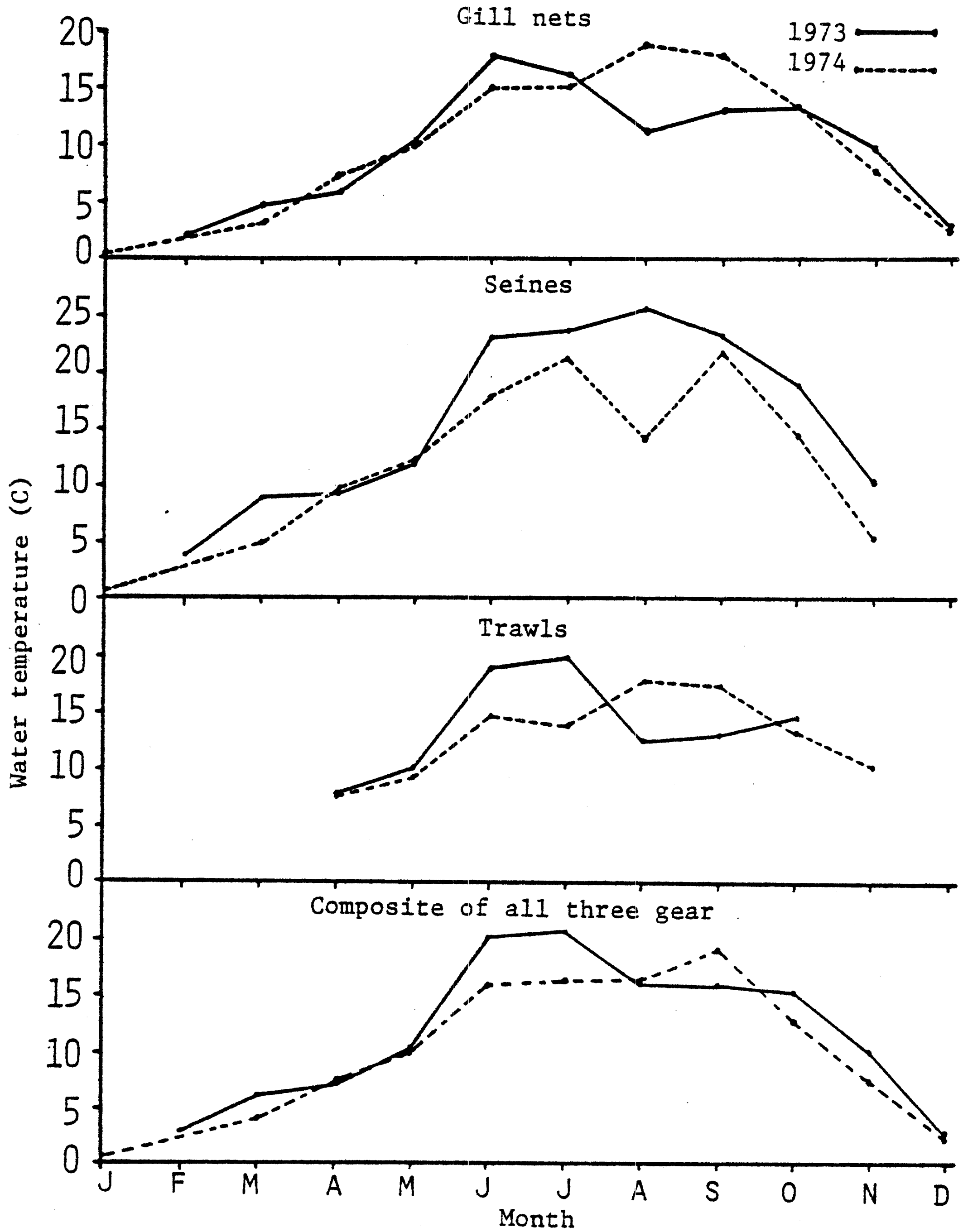


Fig. B15. Mean standard series bottom fishing temperatures by month during 1973 and 1974 in Cook Plant study areas, southeastern Lake Michigan.

Seines -- In 1974, seine collections comprised 66.5% of the standard series alewife catch by number, compared with 84.2% in 1973. A large portion of seined alewives in both years was YOY. When 1973 and 1974 seine data were combined, it was possible to conduct an analysis of variance (ANOVA) in contrast to 1973 when only the less powerful nonparametric Kruskal-Wallis test was feasible. In addition the 1973-1974 seine ANOVA was performed at a .01 significance level, compared with the .05 significance level used for 1973 seine data. For the combined 1973-1974 seine ANOVA the factors YEAR (Y), MONTH (M), STATION (S) and TIME (T) were employed (Table B17). AREA, which was used in the nonparametric analysis of 1973 seine data, was omitted because of redundance with the factor STATION. MONTH was the only significant effect in the 1973-1974 ANOVA. This agreed with the Kruskal-Wallis test of 1973 data which found neither STATION nor AREA significant; only MONTH was a significant main effect in 1973 (Jude et al. 1975). There were four significant two-way interactions in the 1973-1974 ANOVA: YxM, MxT, MxS, and SxT. Significant higher-order interactions were YxMxS, YxMxT, YxSxT and YxMxSxT (Table B17). Interpretation of these complex three- and four-way interactions is at best tenuous. Therefore, biological phenomena responsible for the main effect MONTH and the significant two-way interactions mentioned above will be emphasized in the following discussion.

Seasonal movement of alewives in and out of the beach zone during 1973-1974 accounted for the significance of the main effect MONTH and contributed to significant interactions involving MONTH. Age-size class data (see Seasonal distribution by age-size class) indicated that adults and probably some yearlings exploited the beach zone in spring. Later (July-August) YOY, already present in the beach zone as early as June in larvae tows, became large enough to be taken in seines. In August YOY were seined in large numbers during both years. After August, seine catches, consisting primarily of YOY, generally declined as young alewives moved offshore (Fig. B16).

With regard to the significant YxM interaction (Fig. B16), major differences between the 2 yr occurred in May, September and October. Larger seine catches of alewives in May 1974 were probably due to: (1) more alewives present in that part of the lake than during May 1973 and (2) later inshore movement of alewives in 1974. Large numbers of alewives were seined in April 1973 (Fig. B8, Jude et al. 1975); somewhat warmer beach zone water temperatures early in the year may have caused an earlier inshore migration in 1973. In September 1973 there was a storm which produced rough inshore waters. We attributed low seine catches during that month (three alewives) to the weather (Jude et al. 1975). Larger September 1974 catches (7839 alewives) indicated that this assumption was correct. The discrepancy between October catches in 1973 and 1974 may have been, to some extent, the product of different temperature regimes between 2 yr. In 1974 alewife catches declined at seining stations after September, except at Warren Dunes (Fig. B17). In October 1973, alewives were abundant at all three stations (Fig. B7, Jude et al. 1975), suggesting an earlier offshore migration in 1974. Temperature data showed that beach zone waters were markedly cooler

Table B17. Summary of analysis of variance for alewives caught in seines at Cook Plant study areas from April through October 1973 and 1974.

Source of variation	df	Adjusted mean square[1]	F-statistic
YEAR	1	.18564	.99
MONTH	6	5.84846	31.11**
STATION	2	.13275	.71
TIME of day	1	.10774	.57
YxM	6	8.72643	46.42**
YxS	2	.06846	.36
MxS	12	.98289	5.23**
YxT	1	.85735	4.56
MxT	6	10.59243	56.34**
SxT	2	1.57803	8.39**
YxMxS	12	1.57340	8.37**
YxMxT	6	6.33485	33.70**
YxSxT	2	1.96565	10.46**
MxSxT	12	.40980	2.18
YxMxSxT	12	1.25374	6.67**
Within cell error	83[2]	.18800	

** Significant ($P < .001$).

1 Mean squares were multiplied by harmonic cell size/maximum cell size ($n_h/N = .9882$) to correct for 1 missing observation where the cell mean was substituted.

2 One degree of freedom was subtracted to correct for 1 missing observation where the cell mean was substituted.

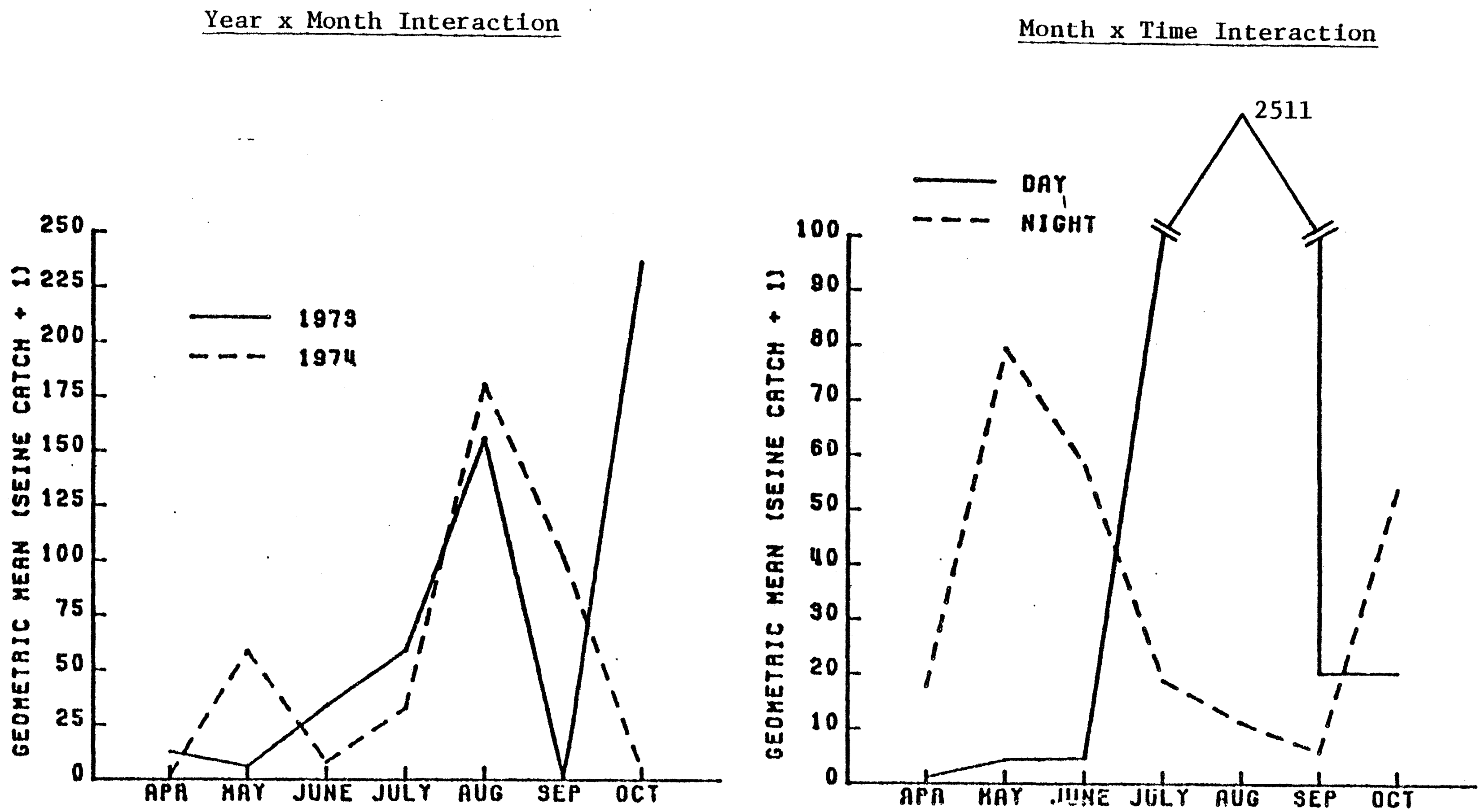


Fig. B16. Geometric mean number of alewives caught in duplicate standard series seines during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

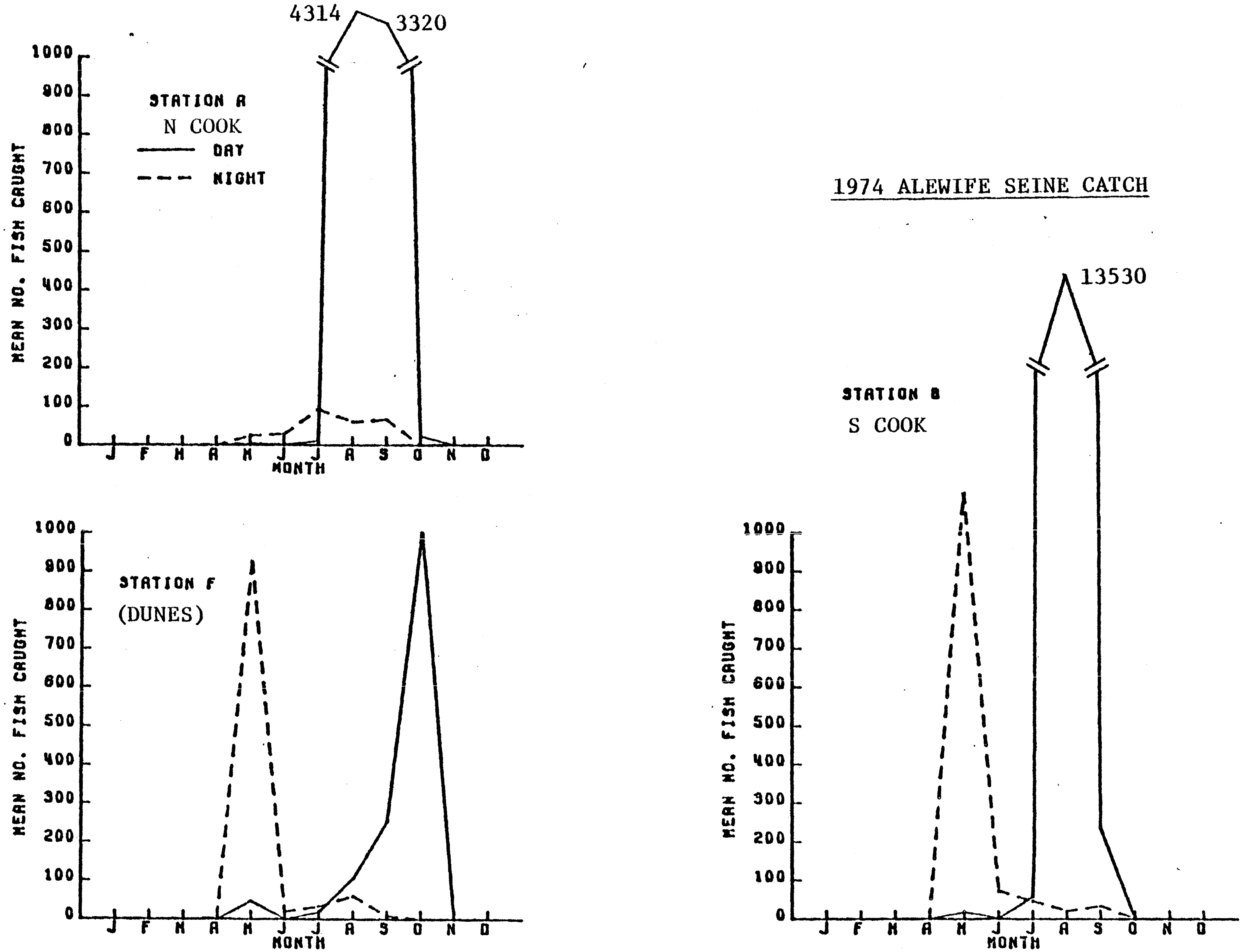


Fig. B17. Mean number of alewives caught in duplicate standard series seines fished during day and night in 1974 at Cook Plant study areas, southeastern Lake Michigan.

after September 1974 than they were in 1973 (Fig. B15). Thus, cooler beach temperatures may have caused YOY (the dominant alewife age-group in fall seines of both years) to move offshore sooner in 1974. Preference of YOY for warmer water is discussed under Temperature-catch relationships. There is some evidence that temperature differences within years as well as between years were involved in the observed October catch variation (see discussion of MxT interaction).

Substantial seasonal differences in alewife diel distribution gave rise to the significant MxT interaction (Fig. B16). YOY comprised most of the large number of day-seined alewives in July (1973-1974) and August (1974). Reasons for preference of this life stage for the beach area in summer are addressed elsewhere (see Seasonal distribution by age-size class). The large spring night catches of April 1973 and May 1974 (Fig. B16) reflected generally nocturnal habitation of the beach zone by adults and probably by some yearlings (Jude et al. 1975, Fig. B8). This diel pattern was not routinely evident in trawl and gill net catches, possibly because of the benthic bias of these gear types and the apparently surface-oriented distribution of alewives at night. A more thorough discussion of alewife diel distribution appears in Statistical analysis -- Trawls. In addition, the MxT interaction was probably affected by the difference in October seine catches between years since there was a large night catch in 1973 (Fig. B8, Jude et al. 1975) and a smaller, predominantly daytime catch in 1974 (Fig. B16). Analysis of the YxM interaction has already indicated that variation in fishing temperatures between 1973 and 1974 may have been involved. However, the large October 1973 night seine catch at all three stations was atypical of alewife YOY which usually reside in the beach zone predominantly during the day. Warmer beach zone temperatures in comparison with water temperatures at 6 and 9 m (Tables B1, B2 and B3, Jude et al. 1975) may have attracted YOY to the beach at night in 1973. An apparent contradiction of this theory occurred in August 1973, when beach temperatures were much warmer than those at 6 and 9 m, yet night seine catches of alewife were low (Tables B1, B2 and B3, Fig. B8, Jude et al. 1975). This paradox is resolved by the fact that August 1973 seining was done 2 wk before trawling and gillnetting. Thus strict comparison of beach zone catches with those at 6 and 9 m is not valid. Alongshore and/or shoreward migration of alewives, associated with cooling of offshore waters in the fall may also have contributed to the apparently atypical night seine catches of October 1973. Reigle (1969) has noted that southward migration of alewives may occur in Lake Michigan as winter approaches.

The significant interactions MxS and SxT demonstrated that, while STATION was not significant as a main effect, there was considerable variation in catch size between stations from month to month (MxS) and from night to day (SxT). No consistent diel or monthly trend of seining station preference emerged over the 2 yr preoperational period, indicating that habitats at the three stations (A,B,F) were probably not the cause of catch variation between stations. Upwellings did not provide a suitable explanation either, since (1) alewives did not regularly exhibit a well-defined response to upwellings at other stations (6 and 9 m - see

Temperature-catch relationships) and (2) only one upwelling has been noted while sampling at seining stations (August 1974), though marked station/catch variation occurred from April through October of both years. Temperature differences between stations exclusive of upwellings were not thought to influence catch differences between seining stations because, within a single month, seining station temperatures during a particular day or night often varied less than 1 C, concomitant with markedly different catch sizes at the three beach stations. Therefore, we suspect that the observed variability of alewife catches between seining stations was the result of very patchy distribution of alewives in the study area. Schooling and other group behavior (for example migration) could account for such uneven distribution patterns.

Gill nets -- Gill net catches of alewives accounted for 12.3% of the 1974 standard series alewife catch, compared to 7.6% in 1973. Parametric statistical testing of 1973-1974 gill net data was not possible because assumptions of normality could not be met. Transformation of the data did not prove effective as a normalizing procedure, so the nonparametric Wilcoxon and Median (Sign) tests were used to evaluate gill net results (see SECTION A). The factors YEAR (Y), AREA (A), DEPTH (D) and TIME of day (T) were examined in both tests at a significance level of 0.10 (Table B18). Seasonal trends, which could not be assessed statistically due to the structure of the tests, were evaluated qualitatively.

The Wilcoxon and Median tests showed no significant difference between years (1973 vs. 1974) or time (day vs. night) for alewife gill net catches (Table B18). A significant difference in amount of alewives caught over depths appeared only in the Wilcoxon test for night fishing at Cook stations in 1973 (Table B18). Catches at 9 m were greater than those at 6 m in that case. There was no corresponding result from the Median test, which does not emphasize differences in the magnitudes of paired catches, which the Wilcoxon test does (see SECTION A). Probably the catch differences that produced significant Wicoxon test results did not occur often enough, month by month, to yield significance in the Median test. This depth difference did not persist into 1974, nor did it extend to include Warren Dunes stations in either year. In all of the alewife data there has been considerable variation between 6- and 9-m catches, both in gill nets (Fig. B6 in Jude et al. 1975; Fig. B18) and in trawls (Fig. B5 in Jude et al. 1975; Fig. B19). Therefore, statistical significance of the depth difference is believed to be an artifact of alewife schooling, vertical migration, or some physical factor rather than evidence of a biological trend of depth preference at Cook stations. Although depth was significant in the Wilcoxon test of 1973 data it was not significant in the Kruskal-Wallis or Mann-Whitney test of 1973 gill net catches (Jude et al. 1975). This discrepancy can be attributed to pairing of the data by month in the Wilcoxon test, which permits much more detailed data examination than the Kruskal-Wallis or Mann-Whitney tests which only evaluate a year's data in total instead of by monthly segments (see Section A).

Area was significant in the Wilcoxon test of 9-m night catches in 1974;

Table B18. Results of Wilcoxon and Median (Sign) tests of paired comparisons of standard series gill net catches of alewife in Cook Plant study areas, southeastern Lake Michigan during 1973 and 1974. Factors were Year, Area, Depth and Time with comparisons in the table given in the same order. Tests were conducted at $\alpha = .10$. NS = Nonsignificant; NT = No test, insufficient non-zero differences.

TEST	TEST RESULTS							
YEAR	Cook Plant				Warren Dunes			
	6M		9M		6M		9M	
	day	night	day	night	day	night	day	night
Wilcoxon	NT	NS	NT	NS	NT	NS	NS	NS
Median	NT	NS	NT	NS	NT	NS	NS	NS
AREA	1973				1974			
	6M		9M		6M		9M	
	day	night	day	night	day	night	day	night
Wilcoxon	NS	NS	NS	NS	NS	NS	NS	Cook>Dunes
Median	NS	NS	NS	NS	NS	NS	NS	NS
DEPTH	1973				1974			
	Cook Plant		Warren Dunes		Cook Plant		Warren Dunes	
	day	night	day	night	day	night	day	night
Wilcoxon	NS	9M>6M	NS	NS	NS	NS	NS	NS
Median	NS	NS	NS	NS	NS	NS	NS	NS
TIME	1973				1974			
	Cook Plant		Warren Dunes		Cook Plant		Warren Dunes	
	6M	9M	6M	9M	6M	9M	6M	9M
Wilcoxon	NS	NS	NS	NS	NS	NS	NS	NS
Median	NS	NS	NS	NS	NS	NS	NS	NS

more alewives were taken at Cook 9-m stations than at Warren Dunes (Table B18). This difference did not appear in 1973, nor was it observed at the 6-m contour in 1974. It is suspected that this result, as with the significant depth effect above, is indicative of uneven alewife distribution in the study area, unrelated to actual biological preference for Cook stations.

Seasonal patterns of alewife gill net catches during 1974, not examined by the nonparametric tests, were generally similar to 1973 catches with respect to occurrence of inshore-offshore seasonal migration. Differences appeared in the later spring inshore movement and spawning migration during 1974 (Fig. B20), which was also shown with trawl data (Fig. B14). Comparison of 1974 gill net and trawl data also showed a discrepancy in seasonal alewife catches between the two gear types, which we believe was

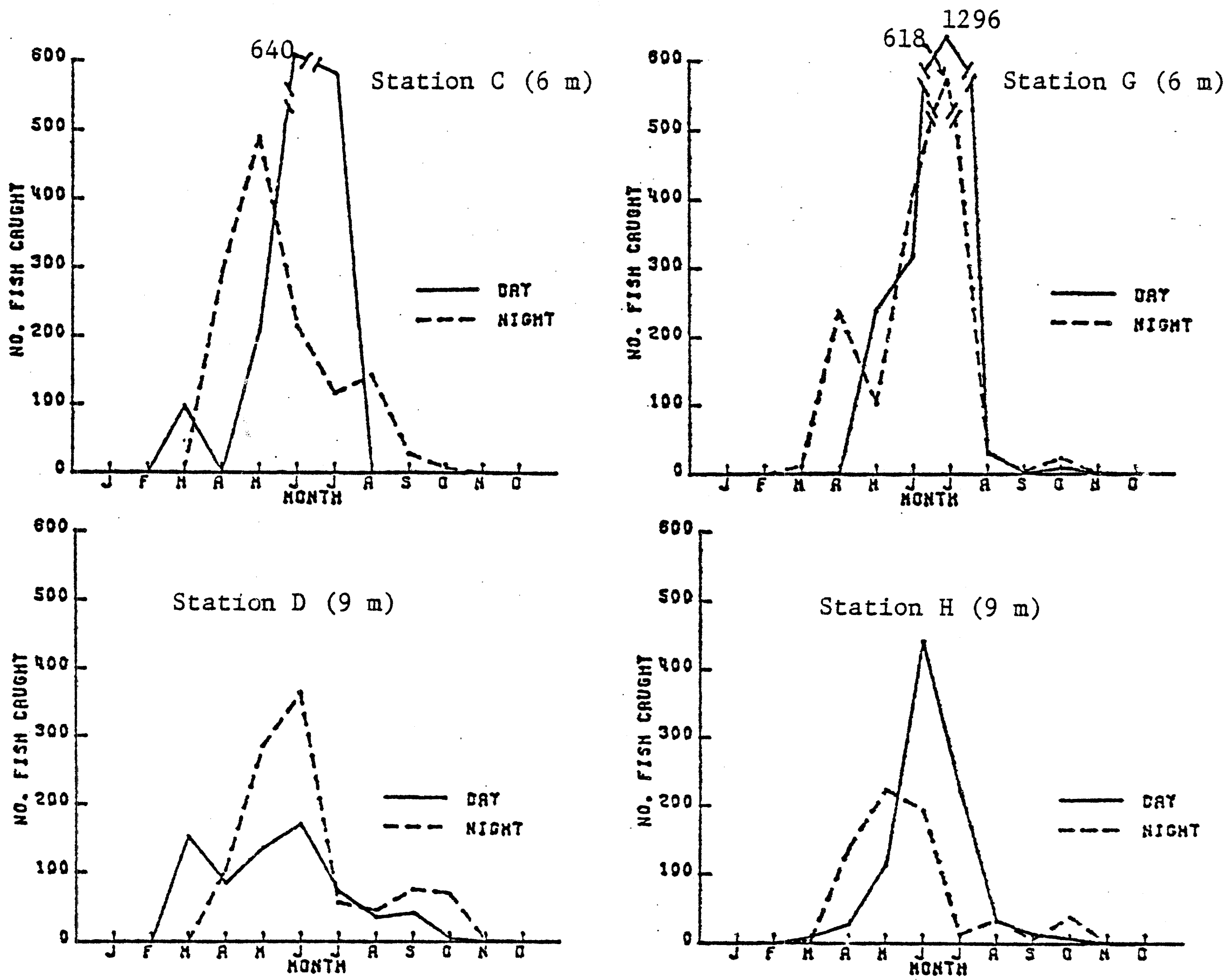


Fig. B18. Number of alewives caught in standard series gill nets set during day and night in 1974 at Cook Plant study areas, southeastern Lake Michigan.

the result of uneven alewife distribution in the study areas. Large alewife trawl catches in April and May 1974 were followed by much lower trawl catches during the rest of the year (Fig. B14). By contrast, gill net catches during that same period, while sizable, did not reach yearly maximum levels until June and July (Fig. B20). Fishing temperatures did not account for the observed difference in catches between gear types (Fig. B15). Age-size class data (Figs. B19 and B21) showed that 1974 catches in both gill nets and trawls during April-July consisted primarily of alewives in the 160-190-mm length interval (155-194 mm). Within this group, most alewives were 170-180 mm. Thus our data indicated that the differences in catches by gear type were not due to different major size classes being sampled by each gear respectively. Examination of alewife catches on a

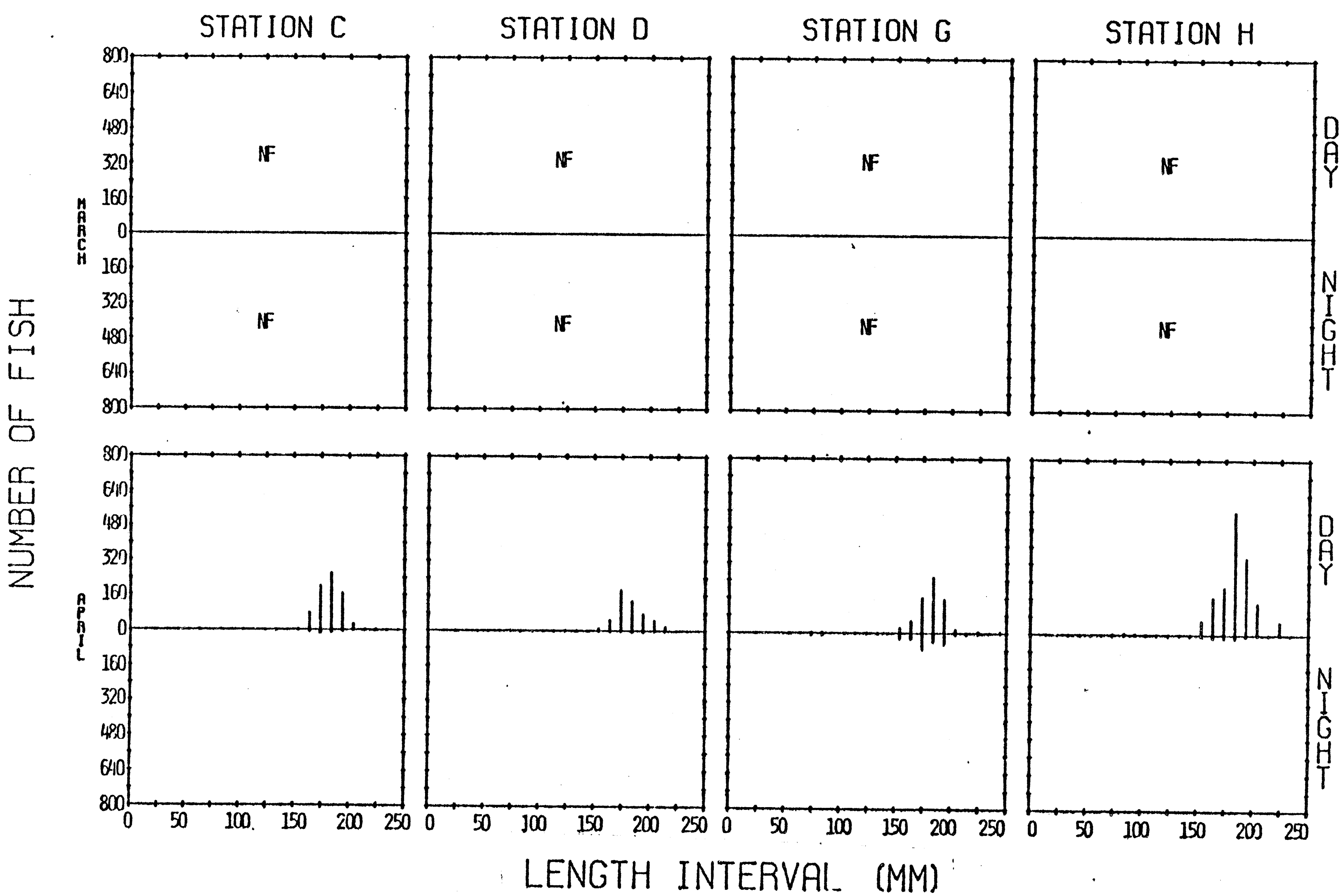
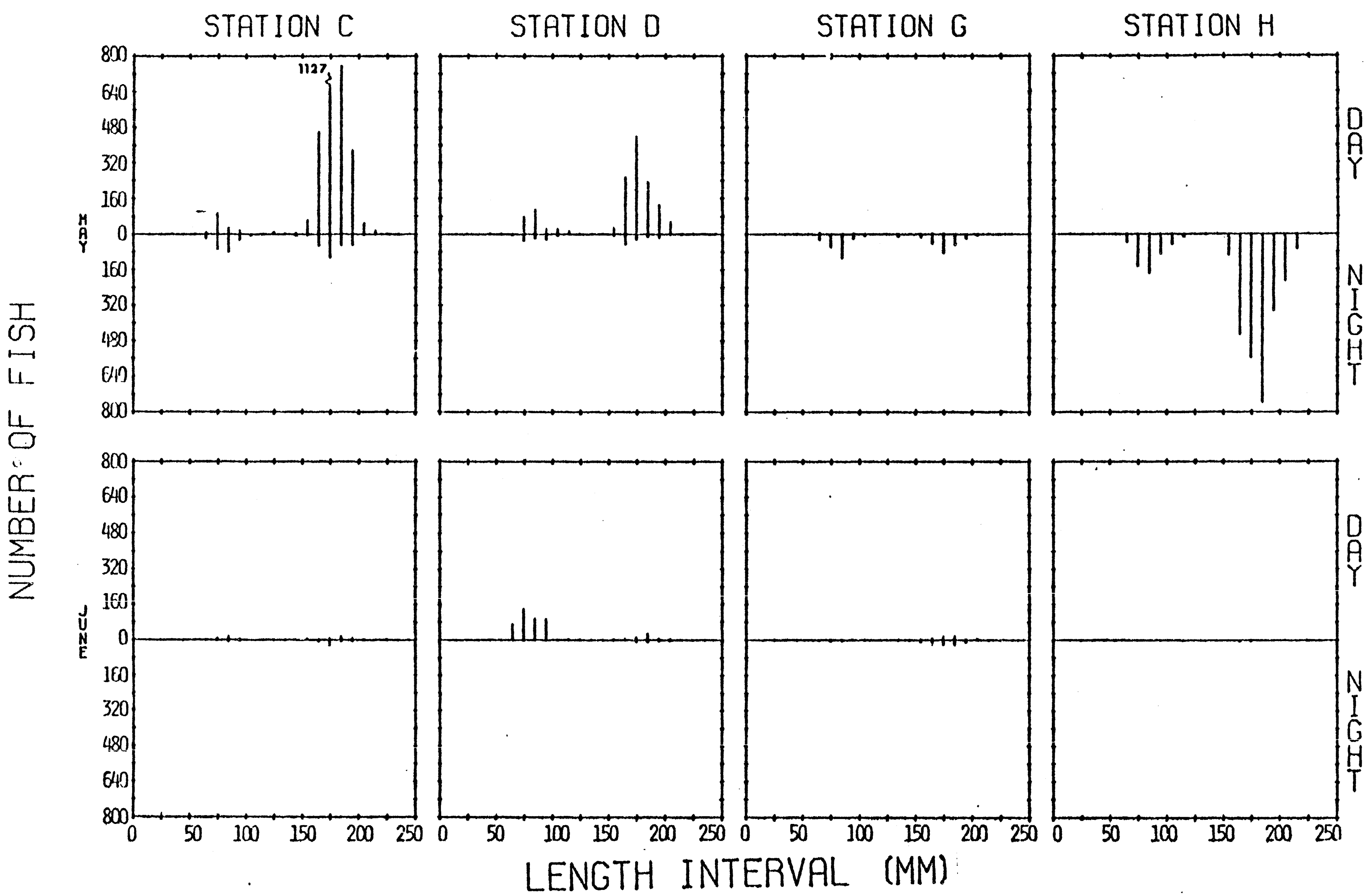


Fig. B19. Length-frequency histograms for alewives caught by standard series trawling during 1974 at Cook Plant study areas, southeastern Lake Michigan. NF = not fished.



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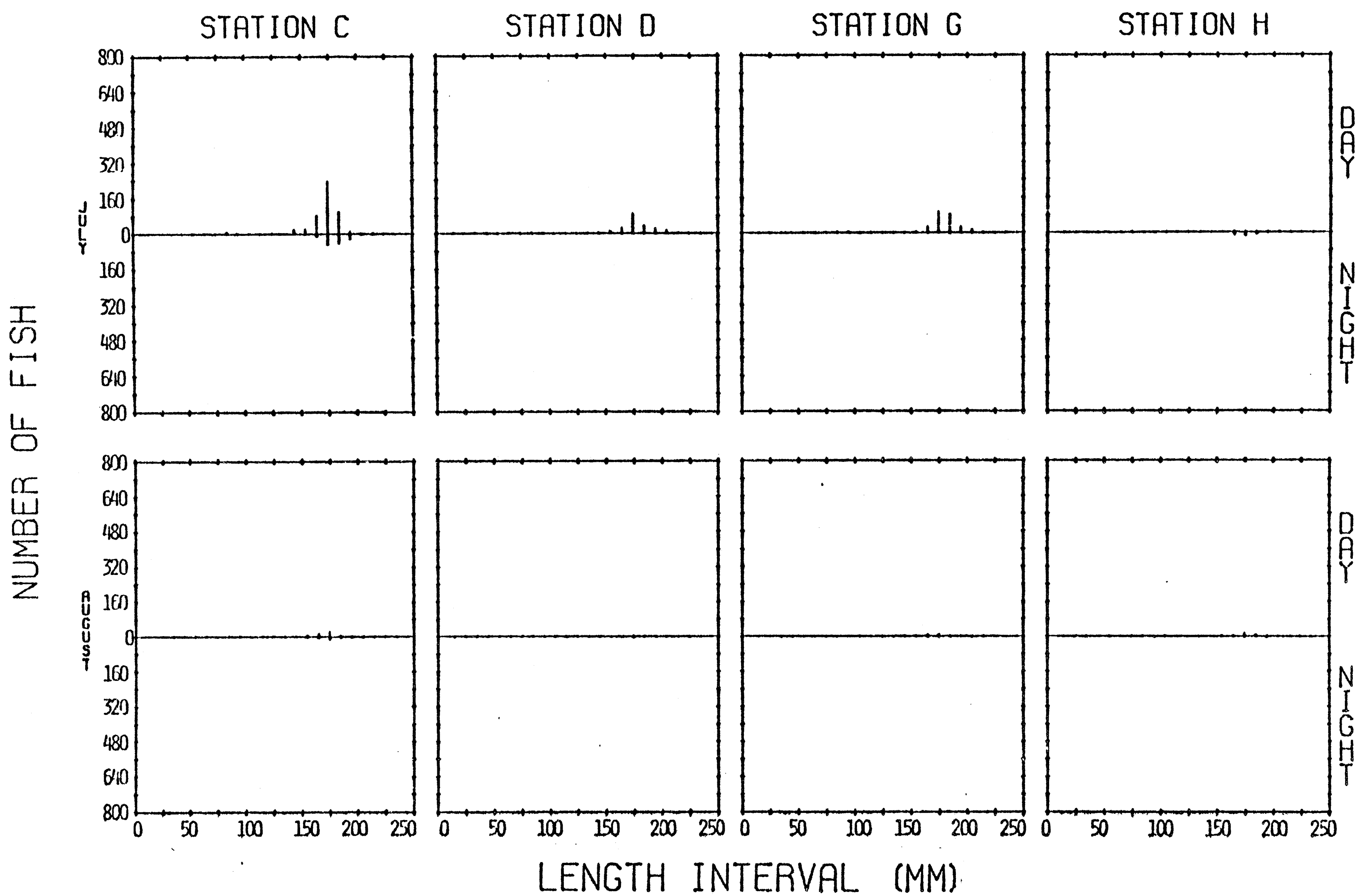

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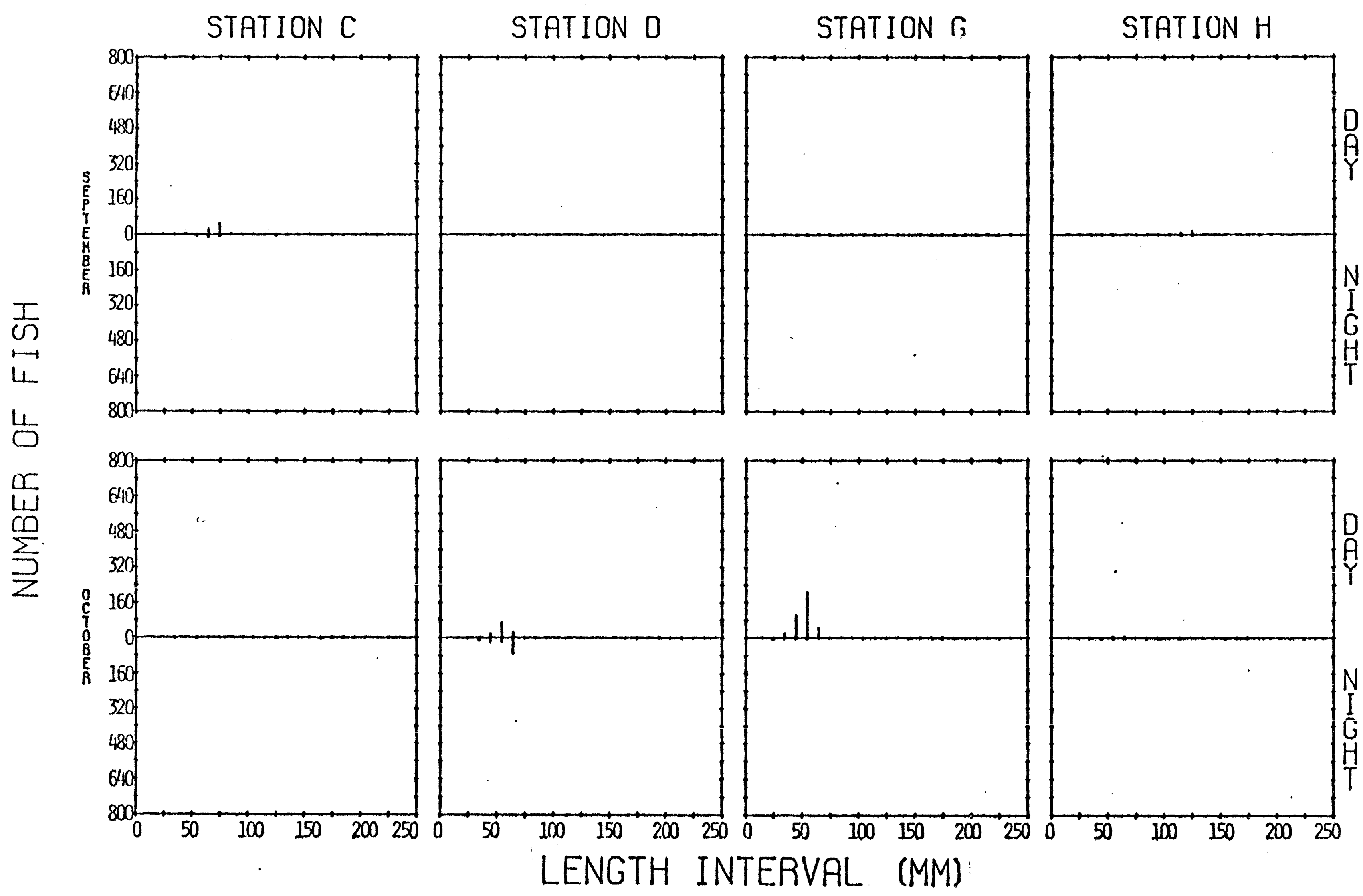

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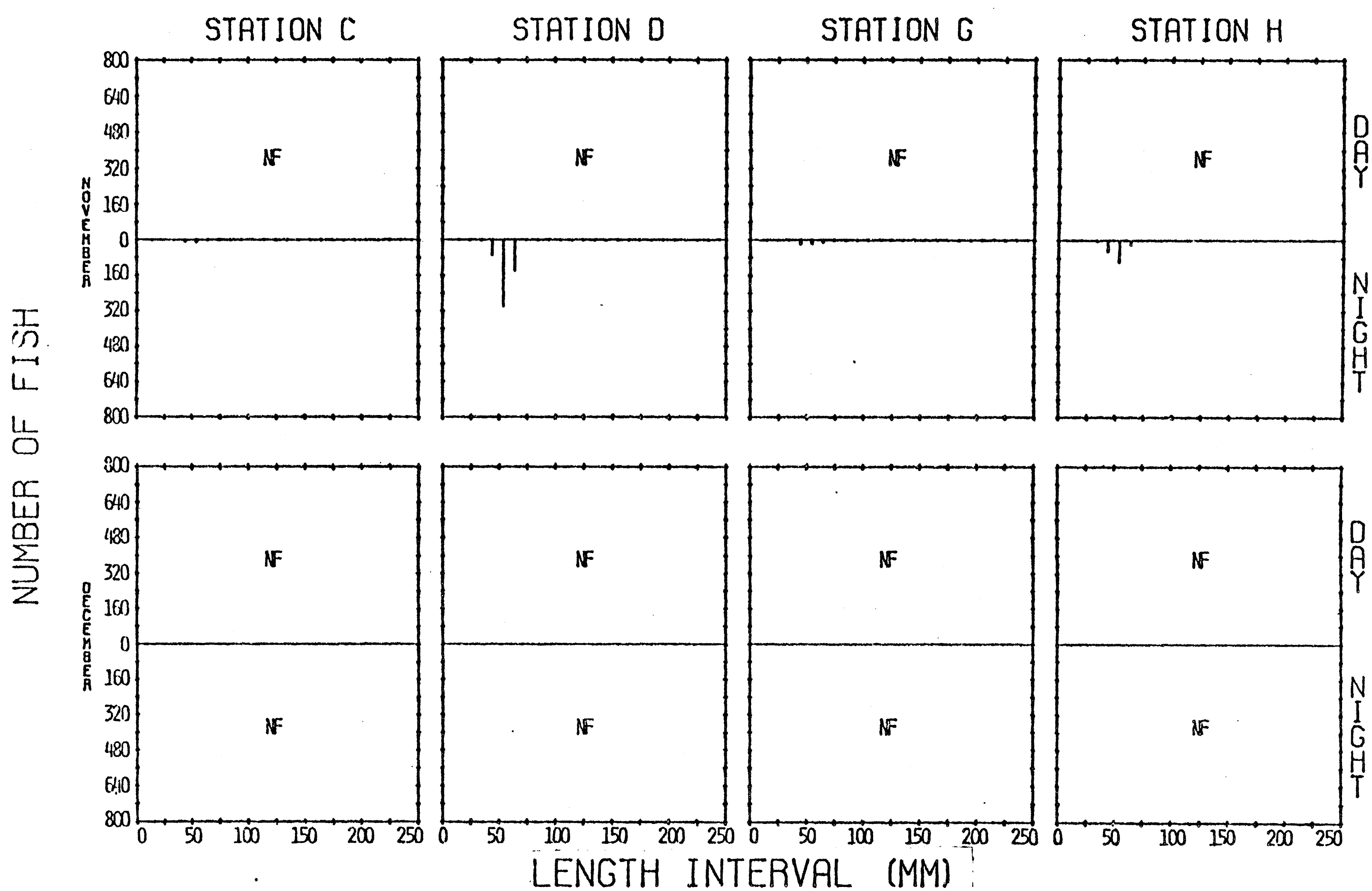

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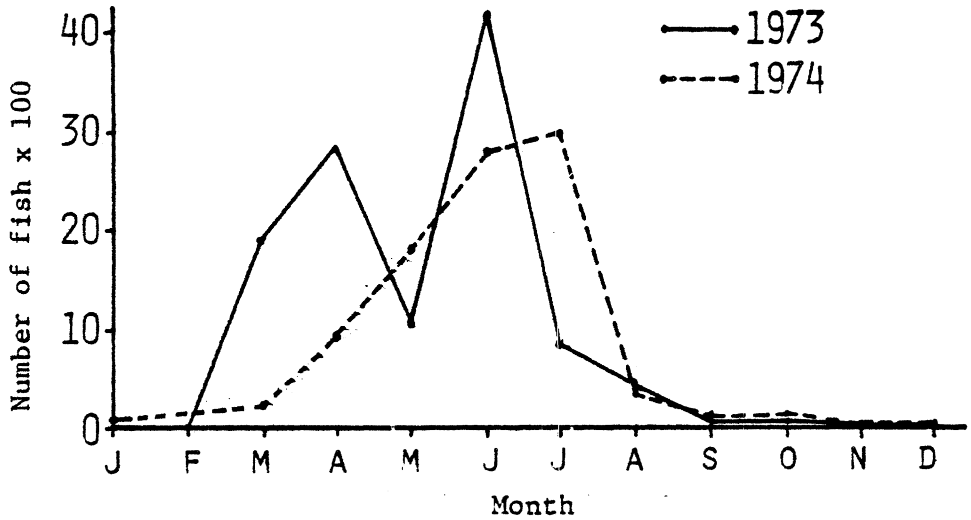


Fig. B20. Total number of alewives caught in standard series gill nets by month during 1973-1974 at Cook Plant study areas, southeastern Lake Michigan. No fishing occurred in January 1973 and February 1974.

station by station basis (Figs. B19 and B21) showed that the April 1974 gill net catch consisted mainly of night-caught alewives, while trawls took alewives mostly in daytime during April. In May, gill net catches were relatively evenly distributed among stations and between diel periods, but trawls had highly uneven catches. Most alewives trawled in May 1974 were taken at Cook stations during the day and at Warren Dunes stations at night. The most likely explanation for the wide variation between alewife trawl and gill net catches is movement of large, dense schools within the study area during spring and early summer. Components of school movement probably include inshore-offshore migration, alongshore migration and vertical migration in and out of the range of gill nets and trawls. The magnitude of this catch variation and the fact that it occurs irrespective of station, diel period and gear type will undoubtedly make detection of plant effects on alewife distribution difficult in the future.

Finally, low catches of alewives in May 1973 gill nets did not recur in 1974 gill nets (Fig. B20), though a similar decline was seen in 1974 trawl catches during June (Fig. B14). Possible reasons for the decrease have been discussed in Jude et al. (1975). Again, differences in catches between the two gear types were probably due to mass movement of alewives in and out of range of our fishing gear.

Seasonal distribution by age-size class --

Young-of-the-year -- Seasonal distribution of YOY has already been discussed to some extent under Statistical analysis. Alewife YOY first appeared in 1974 standard series samples during August, predominantly in seines (Fig. B22); they were last caught in November trawls (Fig. B19). In 1973 YOY were taken in standard series fishing from July through November.

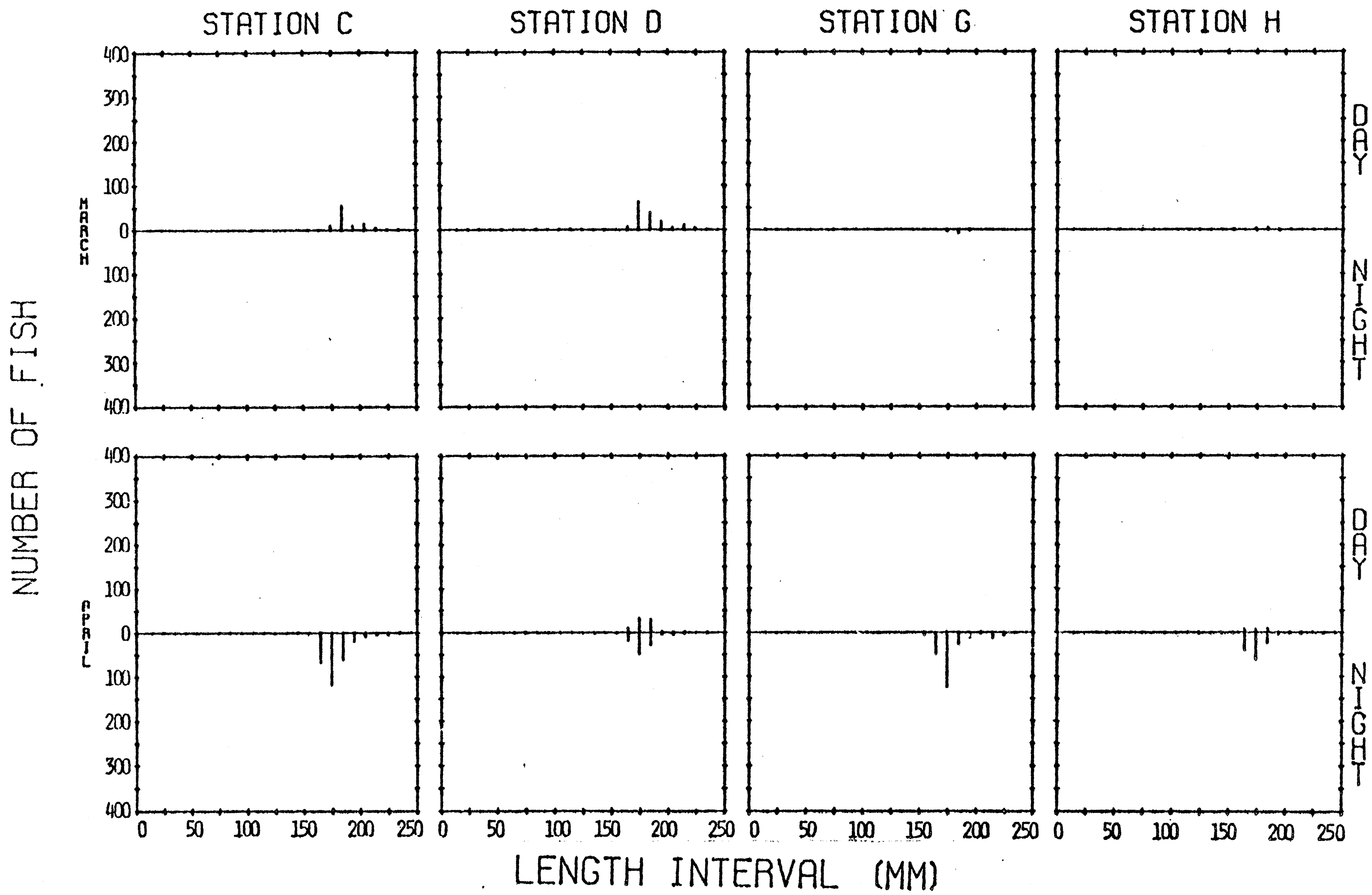
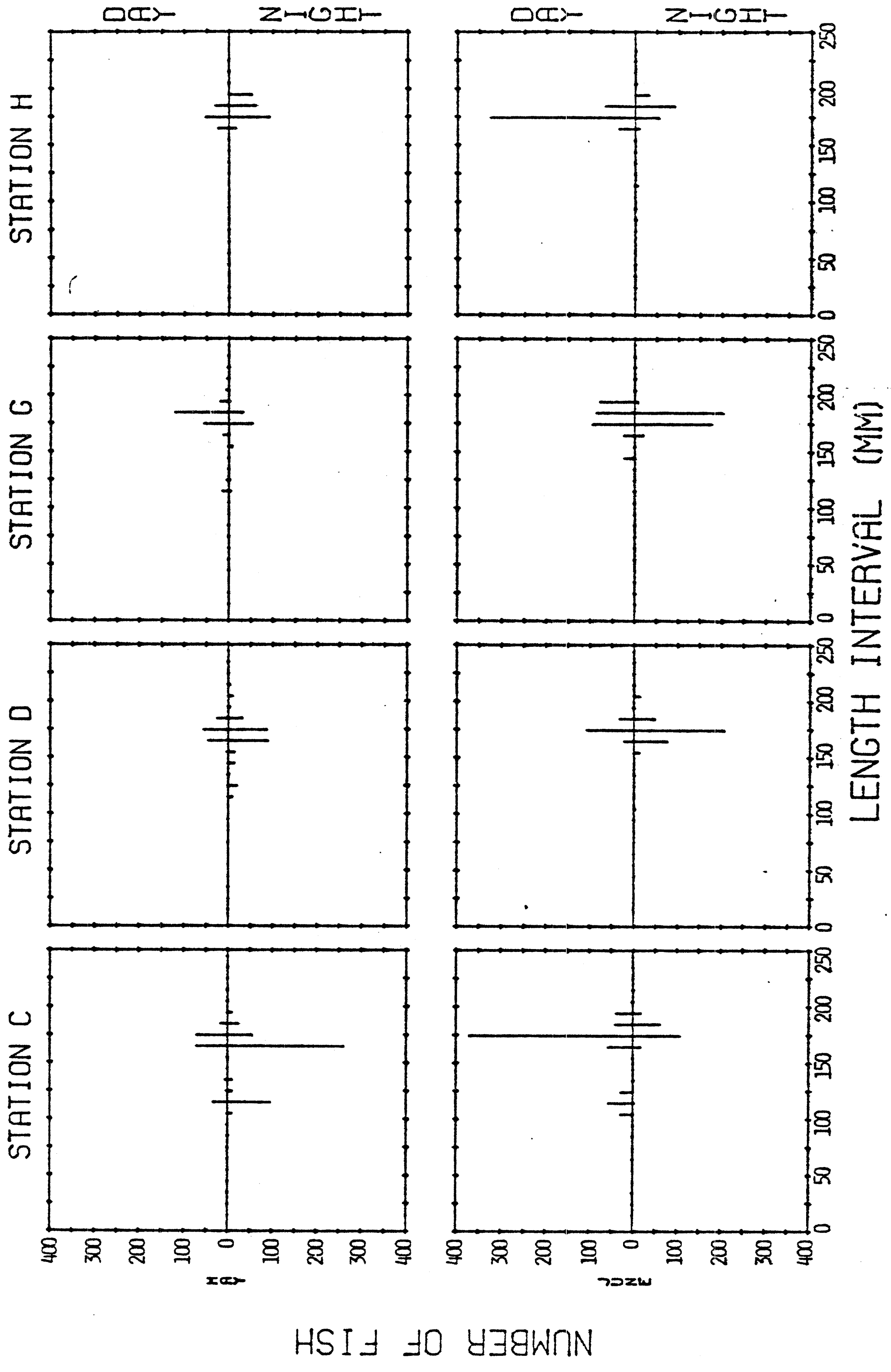


Fig. B21. Length-frequency histograms for alewives caught by standard series gillnetting during 1974 at Cook Plant study areas, southeastern Lake Michigan.



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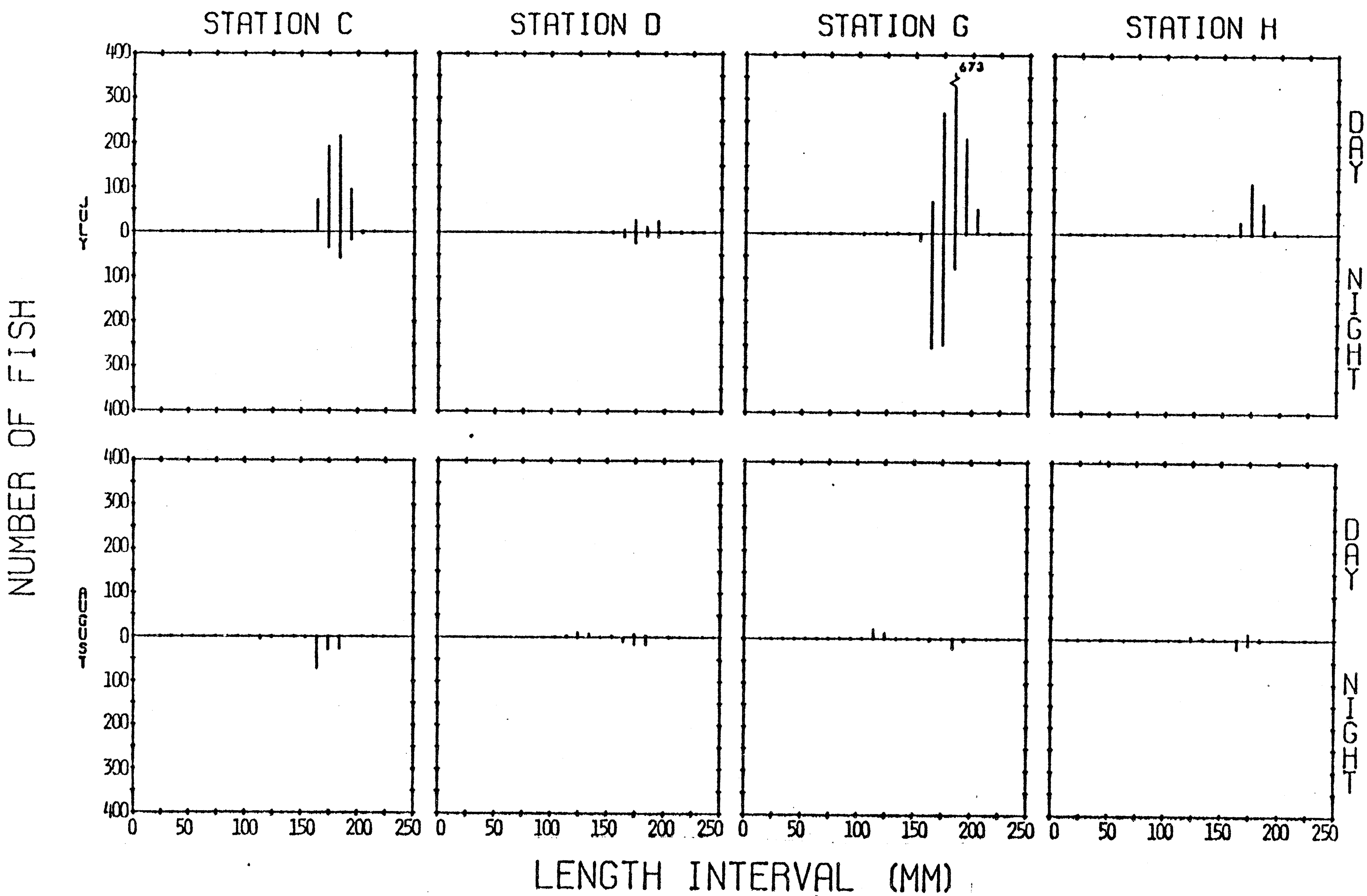

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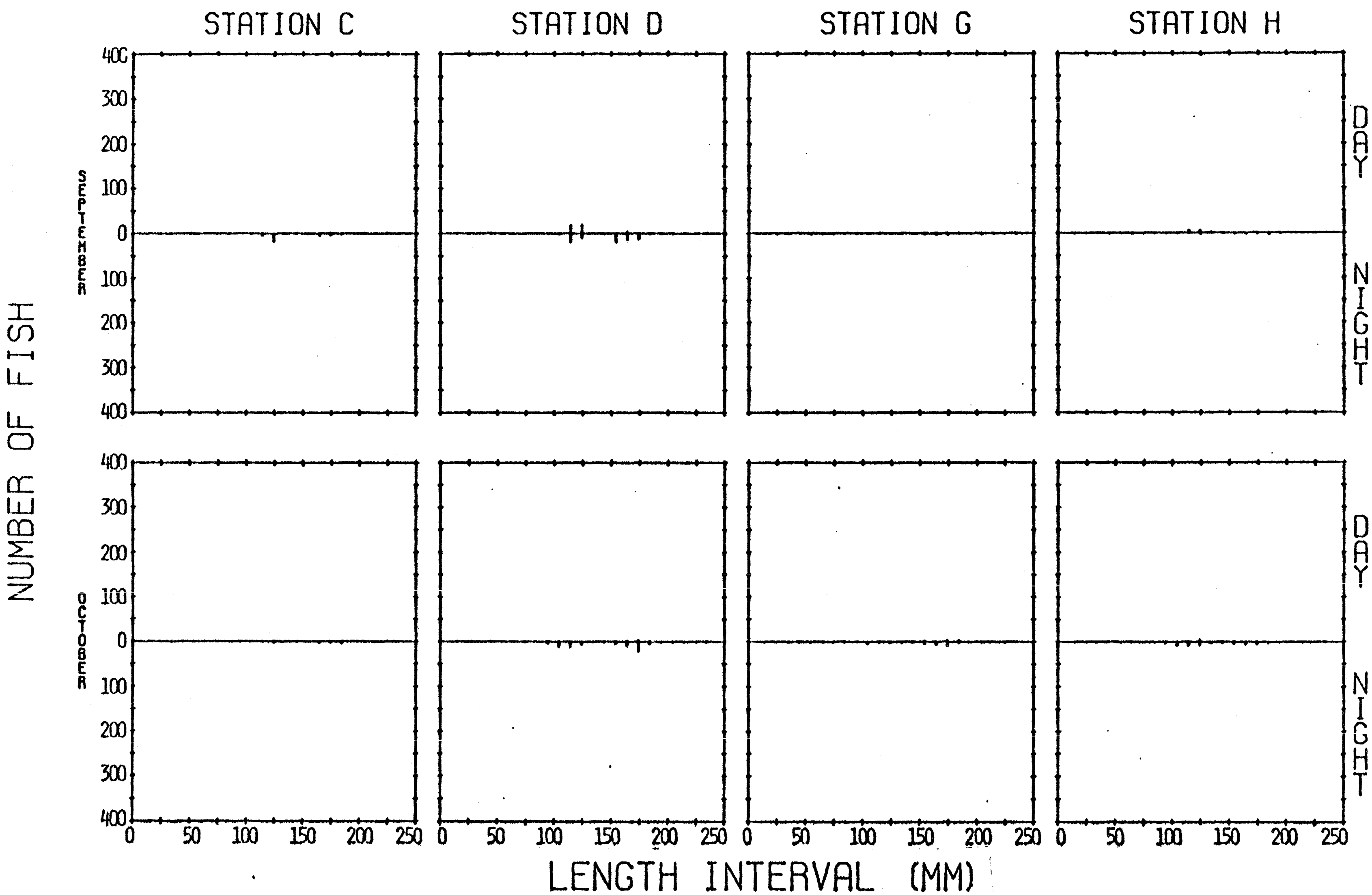

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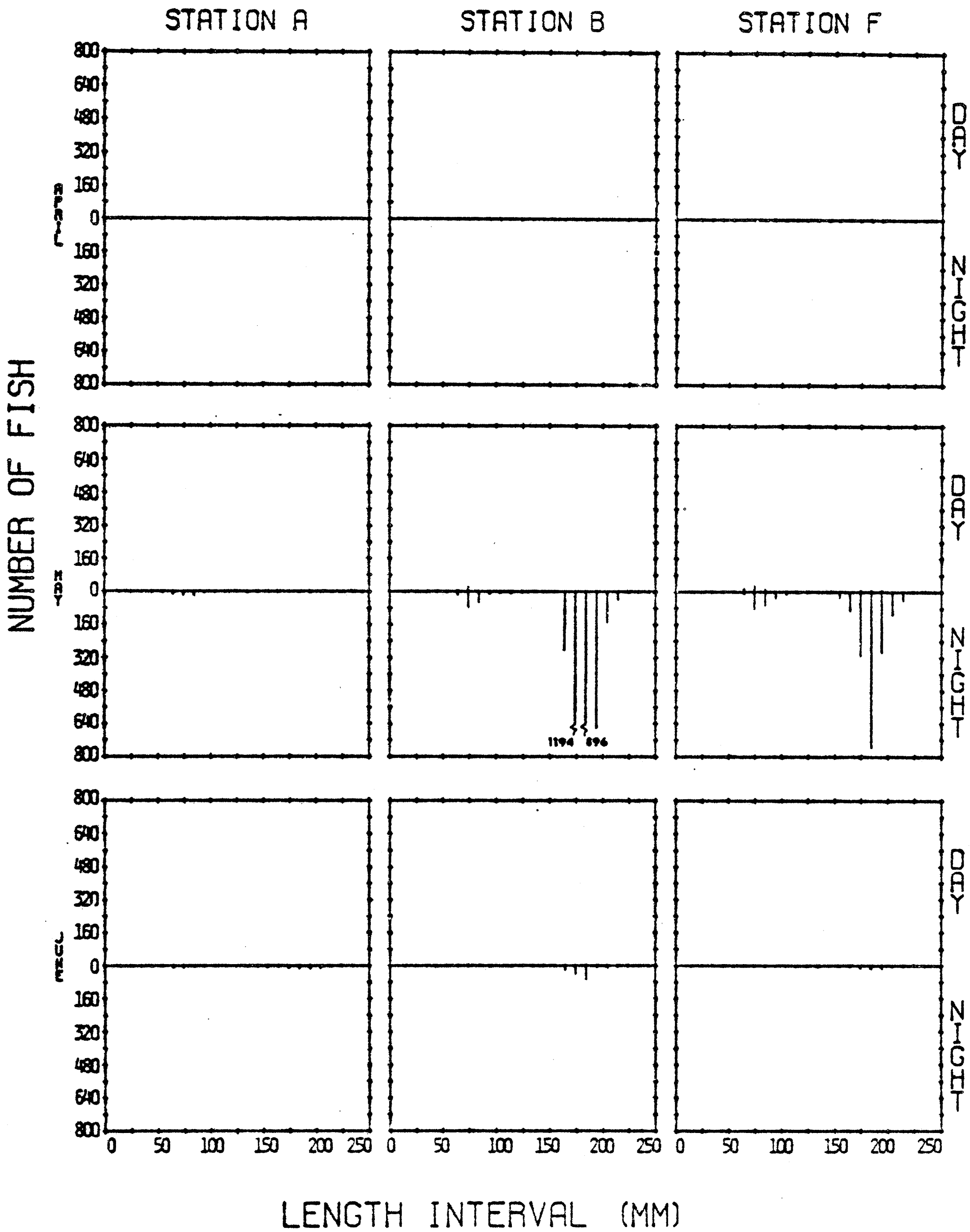
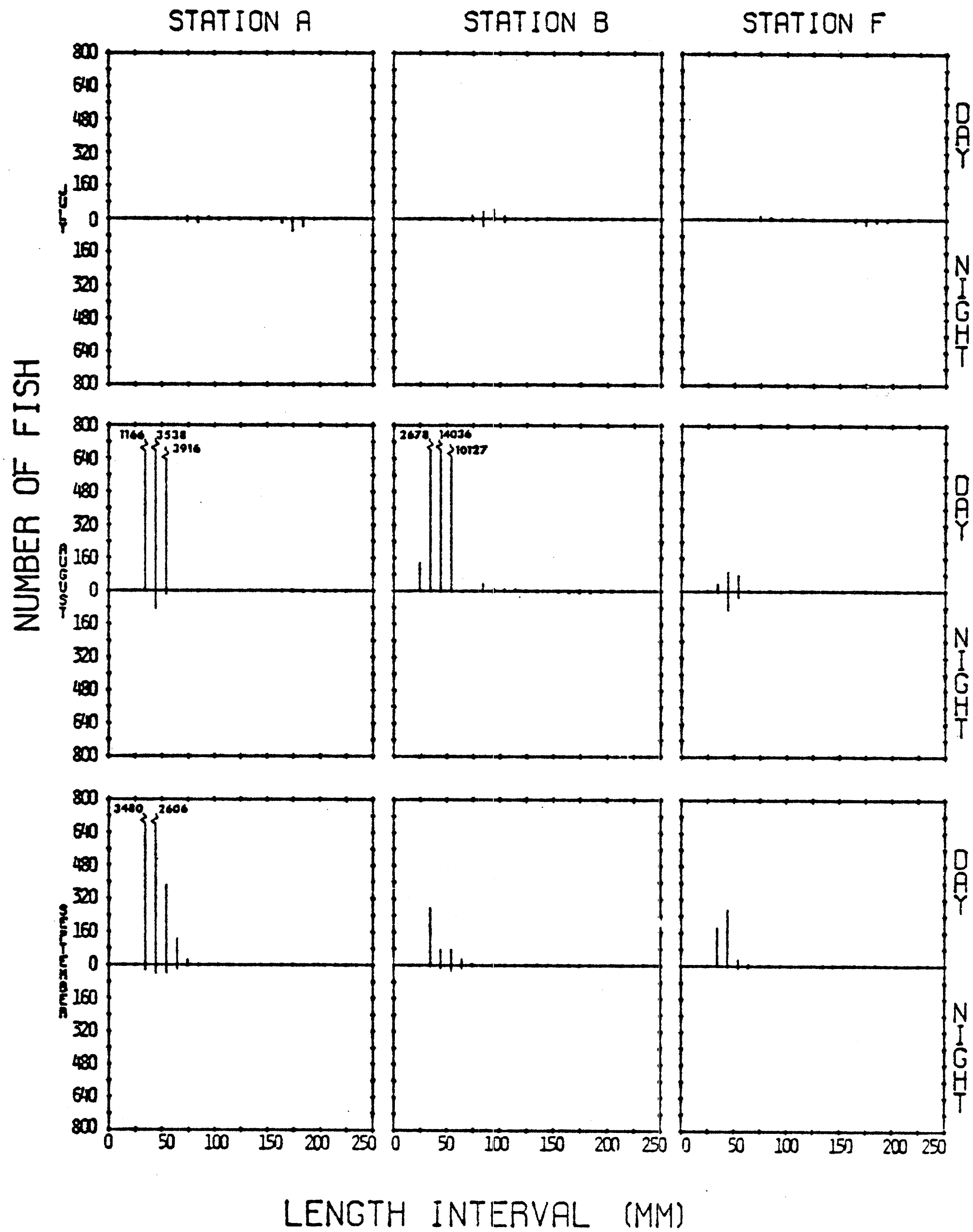


Fig. B22. Length-frequency histograms for alewives caught by standard series seining during 1974 at Cook Plant study areas, southeastern Lake Michigan. NF = not fished.



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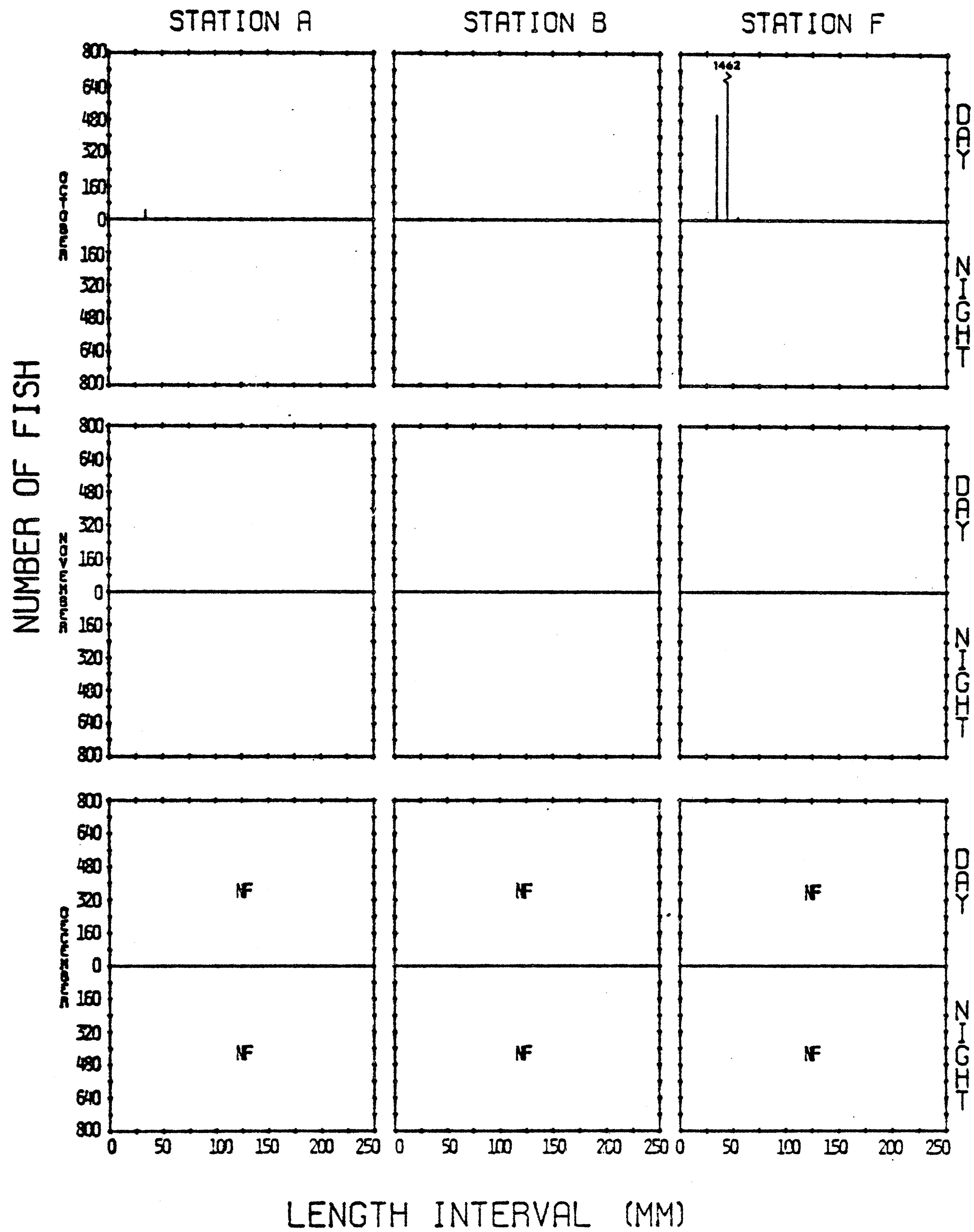


Fig. B22. continued.

During 1974, larvae tows captured alewife YOY June-September, as in 1973 (see SECTION C). Earlier in summer alewife YOY are quite small (average total length in 1974: 5.5 mm in June, 8.4 mm in July) and this was the reason YOY were not caught in standard series gear until July (1973) or August (1974). Larvae tows employ a finer mesh net (363-micron aperature) than standard series fishing gear and thus were more suited to capture of smaller YOY.

In 1974 YOY were less numerous in catches from both adult and larval standard series gear than in 1973 (Fig. B23). Possible explanations for reduction in YOY abundance from 1973 to 1974 include lower spawning season water temperatures in 1974, decreased spawning success in the study area, different mortality rates of YOY between years, year to year variation in alewife alongshore distribution, and strong upwelling in the beach zone during August 1974 sampling. Brown and Wells (1975) documented a similar decrease in YOY alewives from 1973 to 1974 near Benton Harbor, while at three other locations in southern Lake Michigan (Ludington, Saugatuck, Waukegan), YOY increased in number.

As in 1973, day-caught YOY usually predominated over night-caught individuals during summer. During fall of both years the majority of YOY were still taken in daytime but some also appeared in night seines and trawls (see Statistical analysis). Most YOY were captured in seines, indicating dense beach zone concentration of this life stage during daytime in summer and early fall (Fig. B22). We believe alewife YOY frequented the beach zone during the day because of the warmer water there. Our data suggest that young alewives preferred higher temperatures than older fish (see Temperature-catch relationships), a trend also noted by Otto et al. (1976) in their study of Lake Michigan alewives. Positive phototaxis could also be involved in daytime shoreward movement of alewife YOY.

After August 1974, YOY seine catches diminished and trawl catches of YOY increased somewhat (Figs. B19 and B22). We attributed this pattern both to the approach of colder weather and to characteristic migration of older YOY alewives to deeper water (Brown 1972, Wells 1968, Smith 1968b). In November YOY were trawled but not seined as the last of them left the beach zone (Figs. B19 and B22). September seine catches, nearly zero in 1973 because of rough weather, were much higher in 1974, showing that alewife YOY normally inhabit the beach zone in September.

Modal sizes of YOY in 1974 were as follows: August 40 mm, September 30 mm, October 40 mm, and November 50 mm (Fig. B24). These values differed to some degree from 1973 modes which were: July 20-30 mm, August 40 mm, October 50-60 mm (Jude et al. 1975). There was no modal value for September 1973 due to very low catches of YOY. No YOY were taken in July 1974 standard series samples. Later appearance of alewife YOY in 1974 standard series fishing and smaller YOY size in October suggested that spawning occurred later in 1974 than during 1973. Later spawning was also indicated by our alewife gonad data (see Adults) and by larvae tow data. Alewife larvae in 1974 were smaller on a monthly basis than in 1973, both in open water and

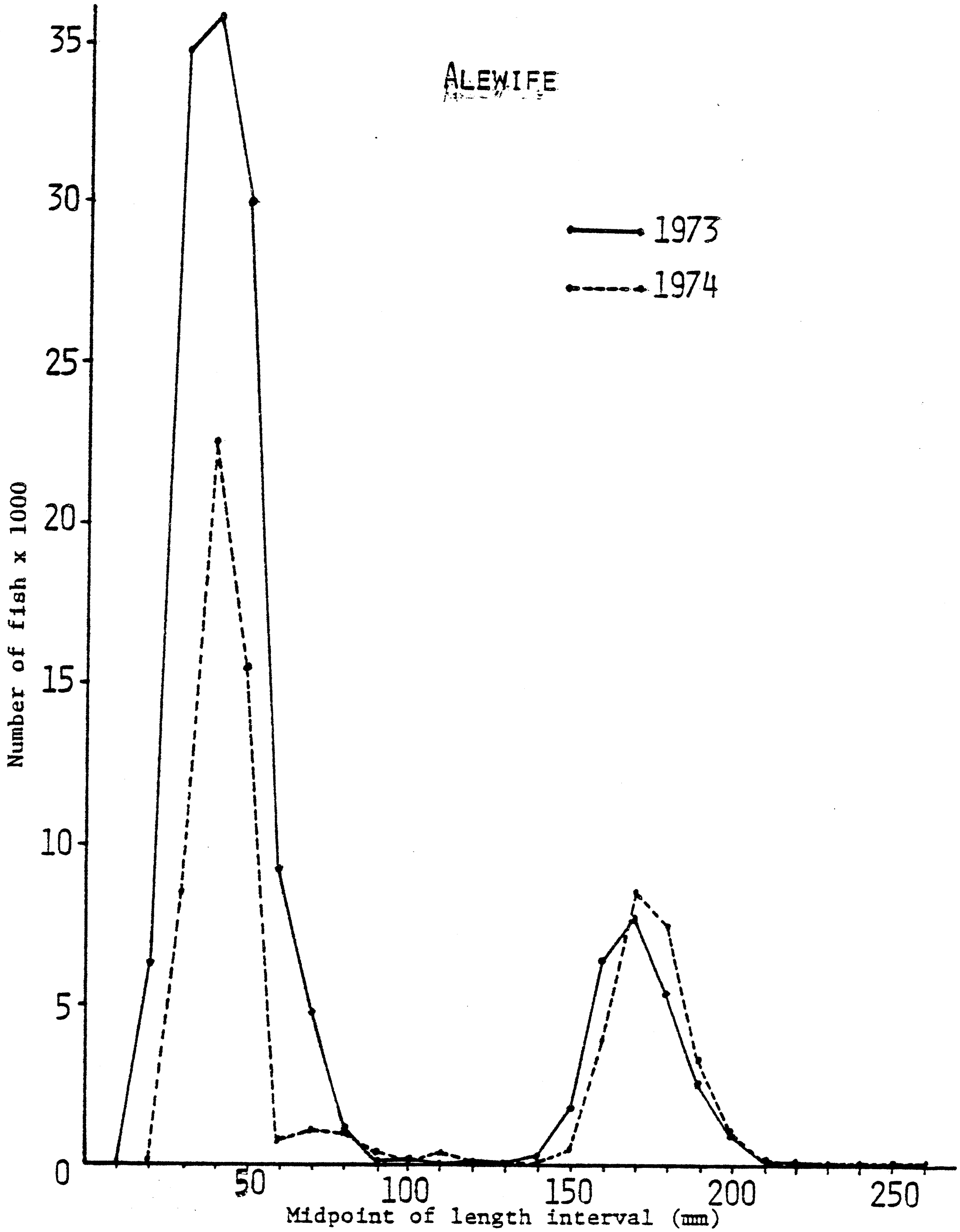


Fig. B23. Comparison of 1973 and 1974 total standard series catch of alewives by length interval at Cook Plant study areas, southeastern Lake Michigan.

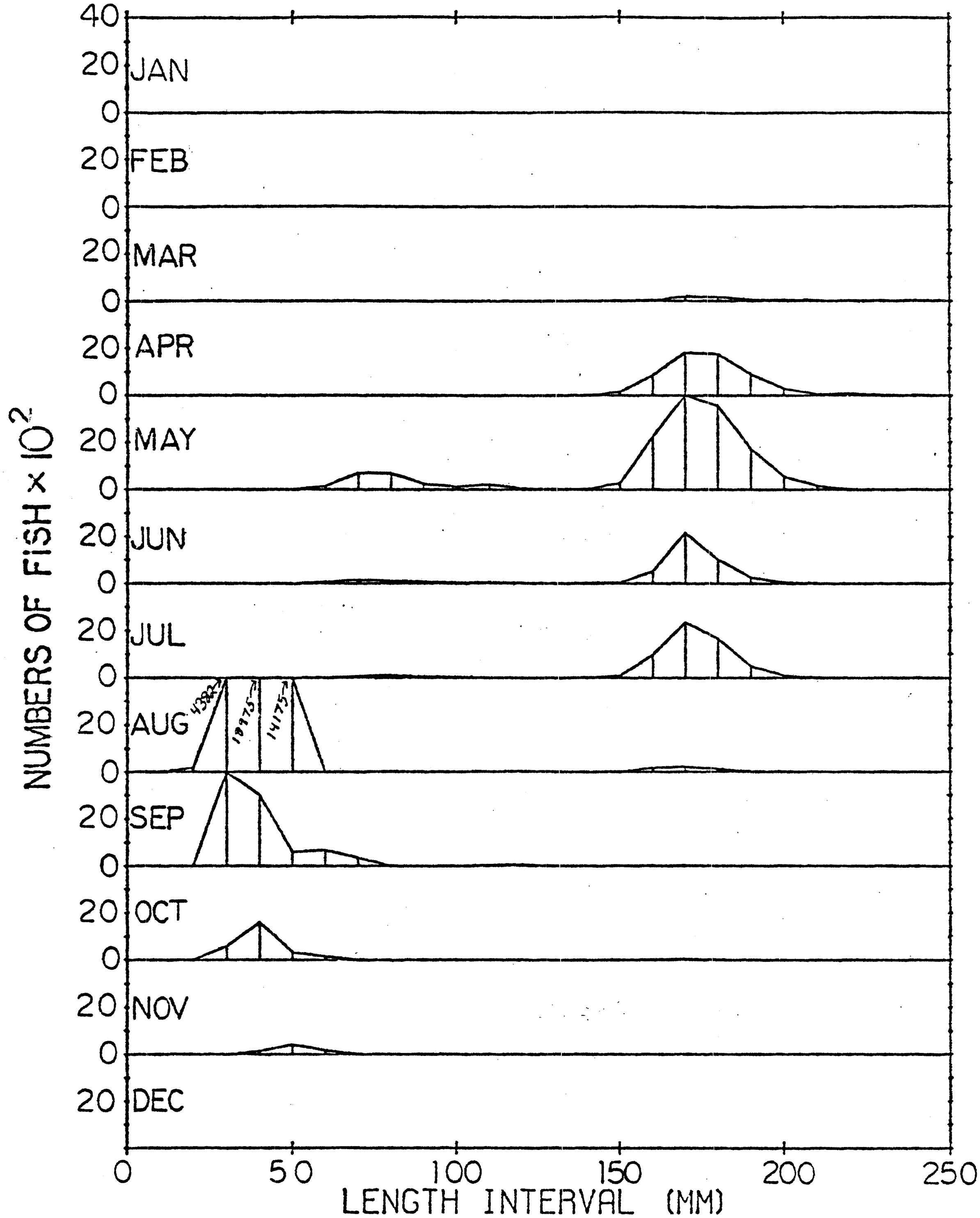


Fig. B24. Composite monthly length-frequency histogram of all field-caught alewives collected during 1974 at Cook Plant study areas, southeastern Lake Michigan.

beach zone samples (see SECTION C).

Adults -- During January and February, when lake temperatures are at their lowest (Fig. B6), most alewives reside in the deepest parts of Lake Michigan where warmer water is found (Wells 1968, Smith 1968a,b, Reigle 1969). In our limited standard series fishing during January 1974, adult alewives were not caught in gill nets or seines though four alewives appeared in 1974 impingement samples during January and February. No standard series sampling was done in February 1974 but we presumed alewives were scarce in the study area as in February 1973. By March adults were captured at gill net stations (Fig. B21) and continued to move inshore in April when alewives were taken in the first trawls performed in 1974 and in gill nets (Figs. B21 and B19). The beach zone remained largely unoccupied by adult alewives until May. The biggest catches of 1974 alewife adults occurred in May when large numbers of alewives were taken in all three gear types (Figs. B19, B21 and B22). We attributed spring shoreward movement of alewives to attraction of the warming inshore waters, though Reigle (1969) considered spring migration (April) as part of the spawning run. Very low numbers of spent alewives in our gonad data for March-May of both years (Table B19 and Jude et al. 1975, Table B12) indicated that spawning probably was not the chief activity of alewives that moved into the Cook study area in spring. A similar peak catch of alewives was observed somewhat earlier in 1973 (April).

In June adults were not as abundant in the study area as they were in May (Fig. B24). We expect that offshore temperatures had reached more optimal levels by June, inducing adults to move from the study area back into deeper water as they did in 1973. Numerous fish with well-developed gonads but few spent alewives were observed in June 1974, compared with an abundance of fish with well-developed and spent gonads noted in July (Table B19). In contrast, more spent alewives were observed in June 1973 than in July 1973, indicating that spawning occurred earlier in the study area during 1973 than in 1974. While the July 1974 alewife catch increased moderately over June as adults concentrated inshore for spawning, July catches were not nearly as large as those during May. The difference may be due to presence of many non-spawning fish (juvenile or senescent) in the spring migration, along with those capable of spawning, while the summer peak may be restricted to spawning individuals. The large spring catch may also have included alewives that moved to the southern end of the lake for the winter; Reigle (1969) has presented evidence that such a migration may occur in Lake Michigan. If this were the case, alewives from the northern part of the lake might appear for the spring shoreward migration in response to warmer inshore waters, but would then return to northern waters and would not participate in the spawning run in southeastern Lake Michigan.

After July, adult alewives were a relatively minor part of the inshore alewife population and YOY dominated alewife catches (Fig. B24). Few adults were seined or trawled after July and their numbers in gill nets diminished steadily through fall (Figs. B19, 21 and 22). In November we caught one

Table B19. Monthly gonad conditions of alewife as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1974 at Cook Plant study areas, southeastern Lake Michigan. All fish examined in a month were included except poorly received specimens.

Gonad condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Females						
Poorly dev.	1		8	28	87	10	15	35	31	30	1	1
Mod. dev.			267	391	386	28	23	10	9	11		13
Well dev.	1		18	31	154	147	268	9	1			
Ripe-running							1					
Spent				2	8	5	354	156	24	10		
						Males						
Poorly dev.			14	24	44	10	36	65	21	26		3
Mod. dev.			169	297	336	69	86	31	11	24	2	28
Well dev.	1		12	25	155	397	206	1				
Ripe-running												
Spent				4	4	3	329	227	34	6		
						Unable to Distinguish						
				3	12	5	55	81	24	15		
						Immature						
			2	27	535	73	222	485	572	205	235	27

adult at the Cook 9-m station. Moderate numbers were impinged through late fall and early winter; 119 were impinged in November and 373 in December in 1974 (see SECTION E). Despite low numbers of alewives in November and December standard series catches, preliminary impingement data for 1975-1976 indicate that this species may remain relatively numerous in the study area through December.

From March until August 1974 alewives in the 170-180-mm length interval comprised the predominant adult size class (Fig. B24). This class was first observed in March and April at 6- and 9-m stations (Figs. B19 and B21). In May these fish moved into the beach zone at night (Fig. B22). Most returned offshore in June and July where they were taken in gill nets and trawls. The majority of larger adults left the study area by August. We also observed two smaller modal size classes. May and June gill nets at the Cook 6-m station (Fig. B21) contained alewives in the 110-120-mm length interval which were probably part of a seldom sampled, offshore pelagic population of young alewife adults, mostly yearlings (Brown 1972, Wells 1968, Smith 1968b). Limited numbers of this class also appeared in our catches during other months. A still smaller size class occurred at the 60-90-mm interval in May and July seines. We suspected that these were mainly yearlings from the large class of 1973 YOY and again represented part of a population that was located deeper than 9 m. Neither of the two classes of small alewife adults approached the abundance of the large adults or YOY. In 1973 a similar class of smaller non-YOY alewives appeared in the study area, primarily in April day trawls and in June seines (Jude et al. 1975); most of these were in the 90-100-mm interval.

Temperature-catch relationships -- Alewives displayed a size-dependent temperature relationship in which younger fish were caught in warmer water than older fish (Fig. B25). This was also noted by Otto et al. (1976) for Lake Michigan alewives. Standard series alewives 15-64 mm in total length were taken at mean temperatures of 23.0-26.6 C during 1973-1974, while older alewives were taken at ever decreasing temperatures (Fig. B25). This size-temperature relationship was tested statistically upon 267,978 alewives caught in trawls, gill nets, seines and impingement during 1973-1974. Alewives were divided into four size groups: 15-85 mm, 86-135 mm, 136-185 mm and 186-255 mm. Catches in the four groups were examined over three temperature ranges: 0.9-9.9 C (low), 10.0-17.9 C (medium) and 18.0-27.9 C (high). A Chi-Square test for independence (Rickmer and Todd 1967) indicated highly significant ($p < .0001$) differences among temperature-catch relationships for each alewife size class (Table B20).

Simplex analysis (Snee 1974) employing 90% confidence regions presented catch values according to relative probability of occurrence of each alewife size category in the three temperature ranges defined above. Fig. B26(a) shows location of the three probability axes on the Simplex graph. A value plotted at the center of the Simplex triangle would be equally likely to occur in any of the temperature ranges defined by each vertex. A value close to a vertex would have a high probability of occurring in that temperature category. Simplex analysis resulted in highly significant

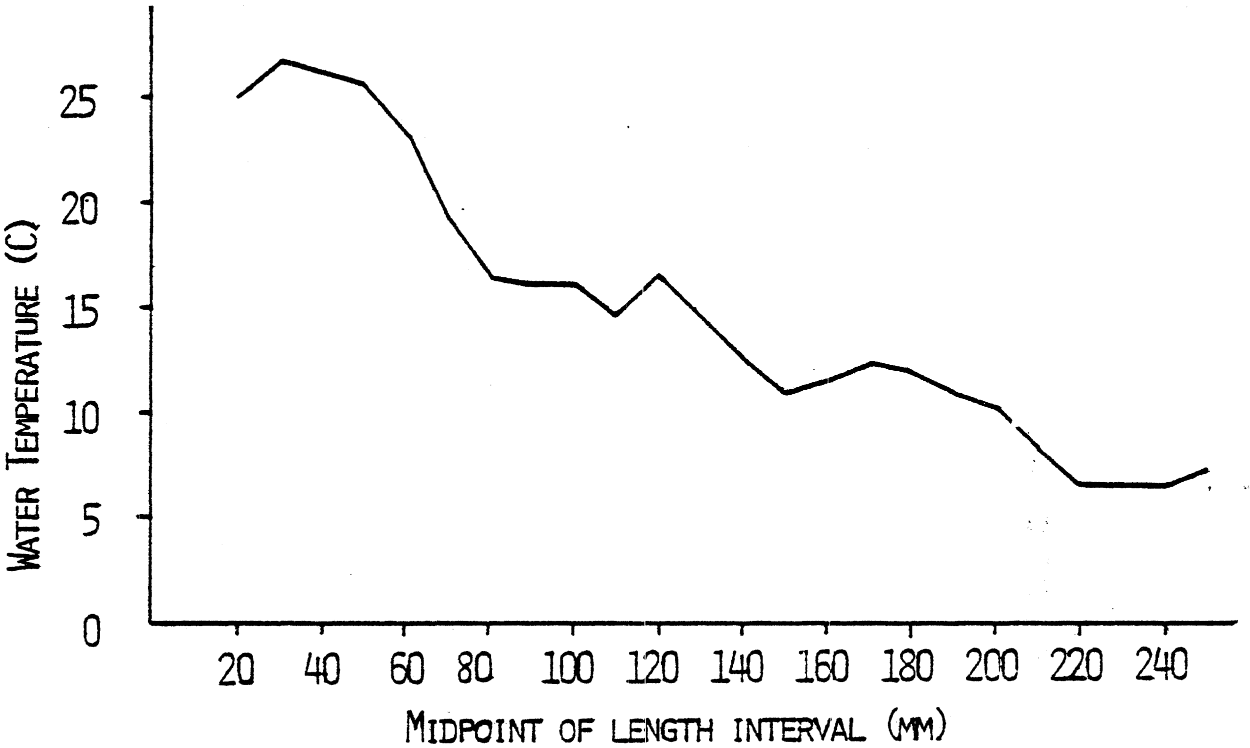


Fig. B25. Mean temperature at which different sizes of alewives were captured during 1973 and 1974 in standard series nets at Cook Plant study areas, southeastern Lake Michigan.

differences between alewife size groups with respect to fishing temperature. This was demonstrated by the small size and lack of overlap of confidence regions, and by the good separation of plotted points corresponding to each size group (Fig. B26(b)). Again the pattern of decreasing alewife size at increasing fishing temperatures was evident. It may be that warmer temperatures fulfill some metabolic requirement of younger alewives, particularly YOY, which are caught most often in the beach zone where the highest temperatures occurred. However YOY were seldom taken at night at beach stations during summer and early fall, even though water temperatures there often remained similar to, or warmer than temperatures at our offshore (6 and 9 m) stations after sundown (Tables B1-3 and Tables B1-3 in Jude et al. 1975). YOY presence in warm beach zone waters was apparently governed in part by diel behavior and was not entirely temperature dependent.

Our observations of alewife size-dependent temperature selection and those of Otto et al. (1976) are contrary to the findings of Wells (1968). Wells stated that alewives showed the least temperature specificity of several fish species he studied in Lake Michigan. Wells evidently sampled a variety of alewife age-size classes simultaneously across wide temperature gradients (5-20 C in one case), which would conceal the trends we have seen. He also did not fish in the warmer beach zone where we caught large numbers of YOY. Based on our findings and those of Otto et al. (1976) we

Table B20. Results of Chi Square test for independence of observed and expected numbers of alewives by size and temperature strata for 1973-1974 fishing in Cook Plant study areas, southeastern Lake Michigan. Includes alewives caught in trawls, gill nets, seines, and those impinged. Expected catch values are in parentheses. X^2 = 90395.1.

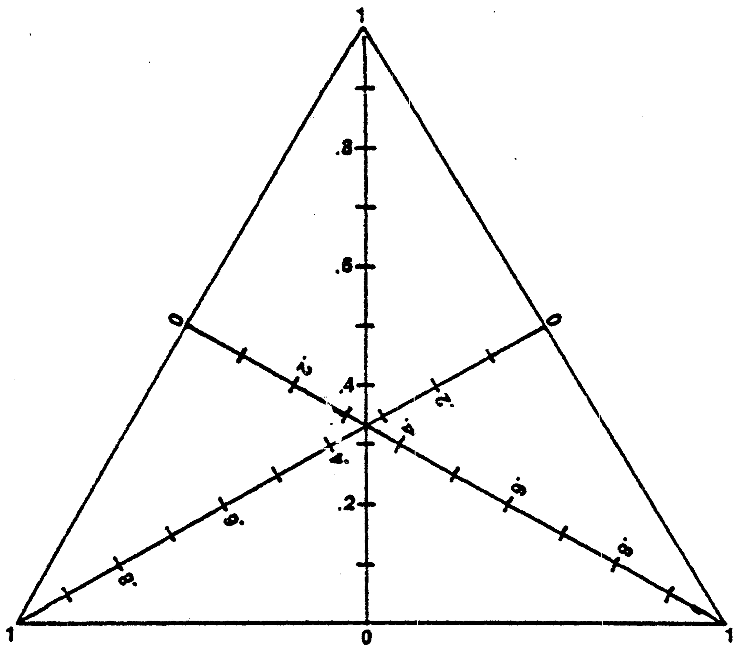
Alewife size-group (total length)	Temperature Strata Low (0-9.9 C)	Medium (10-17.9 C)	High (18-27.9 C)	Totals
15-85 mm	1328 (28157)	60421 (53315)	112881 (93158)	174630
86-135 mm	677 (402)	991 (761)	825 (1330)	2493
136-185 mm	32618 (12174)	17333 (23051)	25552 (40278)	75503
186-255 mm	8586 (2475)	3069 (4687)	3697 (8190)	15352
Totals	43209	81814	142955	267978

might expect attraction of alewife YOY and smaller adult size groups to thermal plumes during operational years, possibly resulting in higher entrainment and impingement rates than observed in the preoperational period. Benda and Gulvas (1976) noted attraction of alewives to the thermal discharge of the Palisades Nuclear Power Plant (located on Lake Michigan), though they were uncertain whether the attraction was due to temperature or to current regimes at the discharge.

Some of the largest catches of alewife adults in both 1973 and 1974 occurred during the spring shoreward migration. Peak standard series spring catches in 1973 were made during April when fishing temperatures were 5.0-9.9 C (mean of 7.5 C). In 1974 the spring catch maximum was in May at 8.4-12.5 C (mean of 10.2 C). Interestingly, April fishing temperatures in 1973 were similar to those of April 1974 (Fig. B15) even though the spring peak occurred later in 1974. Lower water temperatures earlier in that year (March) were thought to be the cause of the later catch peak in 1974.

Mansueti amd Hardy (1967) observed ripe-running alewives in 4.2-16.7 C water in Chesapeake Bay. Our data indicated that spawning occurs at higher

(a)



(b)

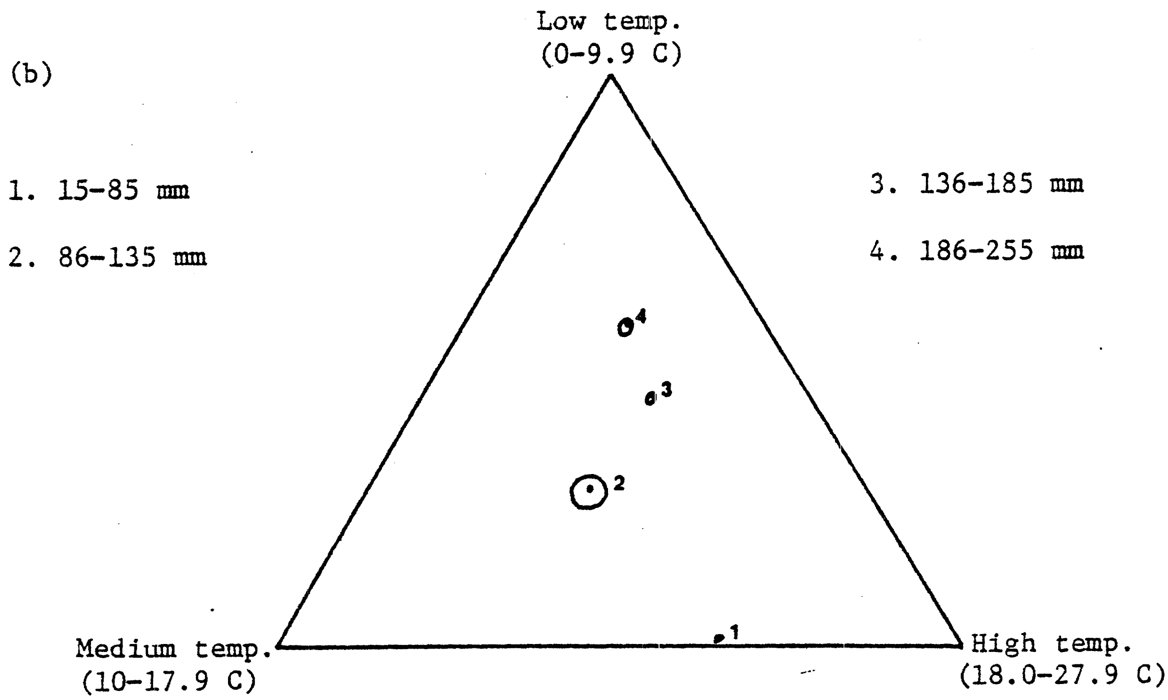


Fig. B26. Simplex analysis of alewife temperature preference. (a) Illustration of two dimensional Simplex space with probability axes drawn. Each axis represents a separate variable or category. (b) Results of alewife Simplex analysis with 90% confidence regions.

temperatures in southeastern Lake Michigan. In 1973 during the June-July spawning season, standard series fishing temperatures ranged from 16.3 to 24.0 C in June (mean of 19.9 C). During July 1973 trawling and gillnetting temperatures together ranged between 11.9 and 22.4 C (mean of 18.7 C). Only about 60 adults were seined in July, thus beach zone temperatures were not thought to accurately reflect spawning temperatures during that month. Somewhat more spawning occurred in June 1973 (Table B12, Jude et al. 1975) than in July. In 1974 spawning occurred mainly during July (Table B19), when the fishing temperature range was 10.2-22.0 C (mean of 16.6 C). Spawning was assumed to reach a maximum when large numbers of well developed, ripe-running and spent individuals appeared in alewife catches. These data do not necessarily demonstrate spawning temperature optima and should serve only as general indicators of alewife spawning temperatures in the study area.

Wells (1968) noted little alewife movement in response to two August upwellings in southeastern Lake Michigan. Emery (1970) in a SCUBA study, reported that alewives in Georgian Bay moved away from cold water during an internal seiche. Our data for adult alewives agreed with that of Wells. Adult alewife catches in the study area did not display consistent patterns that could be related to upwellings in either 1973 or 1974 (see Effects of Upwelling on Fish Distributions).

YOY may be more sensitive than adults to temperature changes produced by upwellings. In August 1973 large numbers of YOY (2241) were trawled at night although in summer they are typically caught during the day in seines. A strong upwelling occurred at that time and colder offshore waters may have forced the YOY to remain inshore and/or at trawling depths that night. During August 1974 there was an upwelling which directly affected the beach zone. Lower daytime catches of alewife YOY in August 1974 may have been in part a result of this upwelling. There were 77,046 YOY caught in August 1973 day seines compared with 35,818 in August 1974. However 1974 YOY catches were lower generally and probably also arose from reduced spawning success or less recruitment in 1974.

Finally it should be pointed out that apparent lack of response to changing temperature in this or other species does not imply that the species was unaffected. Emery (1970) observed temperature-induced mortality of sculpins and crayfish which did not leave an area of rapidly cooling water in Georgian Bay. Massive alewife die-offs in the Great Lakes have been attributed to many factors, among them overpopulation, iodine shortage, pituitary imbalance and inability of this species to thermoregulate adequately (Colby 1971 and 1973, Scott and Crossman 1973, Brown 1968, Li and Warner 1972, Stanley and Colby 1971, Smith 1968b).

Other considerations --

Die-offs -- As in 1973, dead alewives were observed during June and July in the study areas. Early in June field crews noted dead alewives floating in the water at the Cook Plant 6-m station (station C). Later that

month dead alewives were seen both in the water and on the beach during seining at Warren Dunes. Those on the beach belonged to two size groups, one 150-200 mm and the other 50-90 mm, and appeared to be newly dead. On the beach near the water line 25-30 per meter were observed. In July dead alewives were noted in the water at the Warren Dunes 6- and 9-m stations. Density was approximately 1/50 m^2. Dead alewives were also common at beach stations both at Cook and Warren Dunes. Consideration of plant impact on alewives will have to take into account this natural mortality which has been well documented in the literature (see Temperature-catch relationships) and whose cause is still unresolved. Alewife die-offs are noted almost yearly in many areas of Lake Michigan. Usually they occur during summer months.

Food web -- During dissection of field-caught fish in 1973-1974 we found alewife remains in the stomachs of brown trout, burbot, channel catfish, chinook salmon, coho salmon, lake trout, northern pike, rainbow trout, smelt, yellow perch and other alewives. Predator species most frequently found with fish remains in their stomachs were yellow perch, lake trout, coho salmon and brown trout (Table B21). Alewife remains occurred in 60% of field-caught lake trout and brown trout containing fish remains. Alewives were found in 61% of the coho and 39% of the yellow perch that had eaten fish (Table B21). A brief literature review of alewife predators is given in Jude et al. 1975. In addition to the species mentioned in that report it should be noted that alewife, spottail shiner and emerald shiner have been observed to feed on alewife eggs in a Lake Michigan tributary (Edsall 1964).

There are many studies of alewife food and feeding behavior in Lake Michigan. Alewives eat primarily zooplankton through much of their life cycle, though larger alewives may also feed upon the benthic amphipod, *Pontoporeia* (Scott and Crossman 1973, Webb and McComish 1974, Morsell and Norden 1968). They appear to select for larger zooplankton, probably by sight, since this preference goes beyond the physical selection imposed by their gill rakers (Norden 1968). Some investigators believe that alewife size-selective predation can significantly change the zooplankton community even in a body of water as large as Lake Michigan (Wells 1970, Gannon 1972).

Diel feeding patterns -- Stomachs of 10,606 adult and immature alewives caught in standard series fishing were evaluated for presence or absence of food and tabulated by diel period (day vs. night). The results are presented in Table B22. Adult and immature categories were based on gonad development. During both 1973 and 1974 we observed that adults seemed to feed more heavily during the day, while immatures fed more at night. This may be a behavioral mechanism to temporally preclude competition between adults and immatures for food. A similar trend was noted for trout-perch whose benthic feeding behavior is quite different from alewife feeding (see Trout-perch section). Since we do not know the residence time of food in alewife stomachs, conclusions regarding the time of maximum feeding activity (day, night) must remain tentative.

Field catch as a preoperational data base -- As an indicator species

Table B21. Fish found with alewives in their stomach during 1973-1974 in Cook Plant study areas, southeastern Lake Michigan. Includes only field-caught fish.

Predator species	Number of predators with fish remains in stomach	Number of predators with alewife remains in stomach	% containing alewife remains
Channel catfish	5	2	40
Burbot	13	2	15
Northern pike	41	15	37
Rainbow smelt	14	10	71
Chinook salmon	8	4	50
Rainbow trout	6	3	50
Brown trout	63	38	60
Yellow perch	104	41	39
Coho salmon	83	51	61
Lake trout	99	59	60
Alewife	5	5	100

for possible plant effects, alewives presented the advantage of being very abundant in the study areas. Thus low numbers of alewives will not be a routine problem in the future when alewife data are analyzed for plant effects. The major problems in 1973-1974 preoperational data interpretation involved: (1) determining whether biological trends in the alewife data varied as a function of temperature or whether they were influenced by other factors. The relationship of water temperature to alewife biology is of importance because of the possible effect thermal discharges from the plant might have upon fish near the plant. During pumping of unheated condenser water in preoperational years, current regimes at the discharge did not appear to affect alewife distribution or behavior in the study area. This was contrary to the findings of Richkus (1975); he noted that alewives were attracted to unheated plumes at nuclear power plants. (2) If the biological patterns were temperature-related, was temperature the main cause or were

Table B22. Tabulation of adult and immature alewives by presence or absence of food in stomachs and by diel period. Includes only standard series alewives caught during 1973-1974 in Cook Plant study areas, southeastern Lake Michigan. Categories of adult and immature were based on gonad development. Stomachs in deteriorated condition were not included.

	Percentage of stomachs with food	Total number examined	Percentage of stomachs with food	Total number examined
		1973		
	Day		Night	
Immatures	46	440	84	374
Adults	78	978	45	802
Total	68	1418	58	1176
		1974		
	Day		Night	
Immatures	50	375	87	482
Adults	72	1037	43	833
Total	67	1394	59	1315

there other influences of equal or greater importance? (3) Variation in catch size and alewife distribution in the study areas related to extensive schooling and to vertical migration was the suspected cause of much of the variability in statistical tests involving the parameters DEPTH (6- and 9-m contours), TIME of day and AREA. These two biological factors may make detection of plant effects on the alewife difficult in the future.

Biological patterns in the alewife catches of 1973-1974 that were influenced by temperature to some extent included: (1) onset, duration and extent of the annual shoreward migration of adults; (2) onset of spawning and month of maximum spawning activity; (3) catches of alewife YOY mainly in warm beach zone waters. Wells (1968) found water temperature to be an important influence on alewife seasonal migrations inshore and offshore in southeastern Lake Michigan. Both the onset of spawning and the incubation time of fish eggs are known to be strongly influenced by water temperature (Edsall 1970, Scott and Crossman 1973). Other important influences on the biological events listed above include: (1) yearly variation in alewife catches in the study areas as a function of lake-wide migrations and abundance; (2) diel activity patterns. While diel activity has been

explored in our analysis of alewife field catches, lakewide migration and abundance as it related to the alewives in the study areas could not be assessed completely by even the most ambitious sampling program without intensive study of the entire lake for a number of years.

Overall, seasonal patterns of alewife abundance in the study areas (MONTH parameter) were a more predictable feature of local alewife biology than the trends of abundance we examined with respect to YEAR, DEPTH, AREA and TIME. However it was clear from the 1973-1974 field data that effects of the Cook Plant on any of the abundance parameters we studied (YEAR, DEPTH, TIME, AREA, MONTH) would have to be sizable in order to be detected against the natural variability of the alewife population in the study areas (see SECTION A). We feel that impingement and entrainment data will present more direct and quantifiable evidence of the extent of plant impact on alewives than will the field data.

Spottail Shiner --

Spottail shiners are benthic minnows of shallow areas of large lakes and rivers. They are found in all the Great Lakes and are abundant in Green Bay and the southeastern region of Lake Michigan (Wells and House 1974). We also found them to be very abundant in the shallow inshore region of southeastern Lake Michigan during 1973 and 1974. The following is a brief summary of our 1973 data on spottails.

In 1973, spottails were caught during every month in which fishing occurred and were the second most abundant fish caught in standard series nets (see Table B6). Catches were low during colder months because most fish were overwintering in deeper water. A shoreward migration began in March and continued until peak abundance was reached in June. Spottails spawned in the study area during June and July. Catches decreased in July as adults began dispersing after spawning. In August, catches again increased because of abundant YOY reaching catchable size. Fall decline of catches from summer peaks was attributed to adults and juveniles leaving the area and decreased abundance of YOY due to natural mortality.

Of the three types of gear used in 1973, seines accounted for the numerical majority (66%) of the total standard series spottail catch (see Tables B11 and B12). Adults were predominantly seined at night while the majority of juveniles and especially YOY were seined during the day. No statistically significant differences were found between stations or between areas (Cook vs. Warren Dunes). Seasonal changes in spottail distribution caused highly significant differences among monthly seine catches.

Gill net catches constituted 18% of the total standard series spottail catch in 1973. Only adults were gillnetted, predominantly at night. No statistically significant differences were found between depths or between areas. Differences in catches among months were highly significant due to seasonal changes in abundance.

Results of ANOVA for spottail trawl catches showed highly significant ($p < 0.01$) main effects due to MONTH, DEPTH and TIME of day. Some of the higher-order interactions were also significant and therefore interpretation of main effects was confounded. Some factors which contributed to the variability were moderate schooling behavior of the fish and dissimilarities in temperature between areas due to upwellings. Trawl data demonstrated two distinct activity patterns of spottail shiners in the study areas. In spring, adults and juveniles migrate inshore; they stay inside the 6-m contour during June and July and then move to deeper water in late summer and fall. The second activity pattern involved diel movements. During spring and fall the fish moved from shallower depths out to the 6-m contour at night. In June and July, they stayed in shallower depths (<6 m) probably because of spawning activity.

Growth of YOY in 1973 was slow (compared to growth reported in the literature) possibly due to competition with alewives for food. However, adult spottails attained very large sizes possibly because of lack of predation by piscivorous fish.

While the above is a brief summary of 1973 findings, a more detailed discussion of the data is in the 1973 report (see Jude et al. 1975). The following will be a summary of the 1974 data followed by a comparison of 1973 and 1974 findings.

In 1974, spottail shiners were the second most abundant fish caught in standard series nets (see Table B9). During winter months (December, January and February), catches were low because fish were overwintering in deeper water. Wells (1968) found spottail shiners to be most abundant between 18 and 27 m during February in southeastern Lake Michigan. Wells' data indicated that spottails do not seek the relatively warmer (4 C) deeper water in colder months. The fish apparently did not range into deep water (35+ m) during any time of the year, but stayed in shallow depths even when temperatures were below 1 C.

The spring inshore migration of spottails began in March 1974 in the study area (see Table B9). Numbers of fish collected increased in April, and by May, spottails were abundant when most of the local population had reached the study areas. Peak abundance of spottails for the year occurred in June. This concentration was undoubtedly due to spawning activity.

Gonad development data indicated that spawning occurred in June and July (Table B23). Spawning did occur in the study area--divers observed spottails spawning on the intake cribs in June 1973; in June 1974, spottail eggs were found in the *Cladophora* on the intake structures (Dorr 1974b, Dorr and Miller 1975). Fish larvae data during 1974 also demonstrated that the majority of spawning occurred in June and July when most larvae were captured (see SECTION C). Newly-hatched larvae were caught during the first week of June through the third week of August, showing some spawning occurred in late May and early August. Wells and House (1974) indicated that spottails in southeastern Lake Michigan spawned from late June to

Table B23. Monthly gonad conditions of spottail shiners as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1974 in southeastern Lake Michigan. All fish examined in a month were included except poorly received specimens.

Gonad condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Females						
Poorly dev.	1		1	6	17	3	18	60	64	13	1	
Mod. dev.			54	115	148	75	36	15	10	105	18	17
Well dev.			12	31	286	414	177	4		7	15	
Ripe-running						18						
Spent			1	1		9	172	135	36	5		
						Males						
Poorly dev.			5	14	40	57	25	54	23	15	11	2
Mod. dev.	1	1	55	38	83	221	14	6	12	17	6	4
Well dev.			5	8	13	15	8			2		
Ripe-running												
Spent						7	73	56	3			
						Unable to distinguish						
			4	8	30	56	121	102	25	14		1
						Immature						
	15	1	35	62	219	187	95	141	71	168	14	8

mid-August in 1964 and mid-July to late August in 1972. These data reveal that spottails spawn over an extended period in southeastern Lake Michigan.

Standard series catches (all gear) were large during July and August of 1974 (see Table B9). Large July catches were probably due to some spawning activities still occurring. The large August catch indicated that some fish remained inshore throughout the summer, even after spawning diminished. Wells (1968) also found the bulk of spottails in southeastern Lake Michigan to be at depths less than 13 m in June, July and August.

Fall catches of spottails decreased drastically from summer peaks. Most adults and juveniles had begun their offshore migration while some YOY were still present inshore. By November, most of the population was outside the study area in deeper water. Wells (1968) found the bulk of spottails in southeastern Lake Michigan at intermediate depths (6-31 m) in October and November.

Of the three gear types, seines accounted for the bulk (77%) of the total standard series spottail catch in 1974 (see Tables B11 and B12). Trawling accounted for 12% and gill netting 11% of the total catch. Most spottails caught with the seine were taken during the day, while higher nocturnal catches predominated in gill net and trawl samples.

Statistical analysis --

Trawls -- Results of ANOVA for spottail shiner trawl catches (Table B24) showed highly significant ($p < 0.01$) main effects due to YEAR, MONTH, DEPTH, and TIME. Differences between areas were not significant. This finding lends confidence to the value of Warren Dunes as a control area. The value of this conclusion was reduced, however, since AREA entered into a third-order interaction MxAxDxT and two other interactions YxMxA and MxA. Factors which contributed to the significance of these interactions were: slightly greater concentrations of spottails at Cook than at Warren Dunes and temperature dissimilarities between areas due to upwellings.

Although catches were not significantly different between Cook and Warren Dunes, in 1973 and 1974, there were greater concentrations of spottails at the Cook area in May, June and July (Fig. B27). Limnological causes for this area difference are unknown. But we can speculate that underwater structures and riprap near the plant may make the Cook area more attractive to spottails for possible spawning habitat in May, June and July.

Reasons for the switch to greater abundance at Warren Dunes in August and September (Fig. B27) remain obscure. Possibly some variation was the result of monthly temperature dissimilarities between years. Upwellings which occurred during trawling in August 1973 and 1974 and September 1973 may have caused different temperature regimes between Cook stations and Warren Dunes stations. For example, the August 1974 bottom temperature at station H (9 m, Warren Dunes) during night trawling was 12.7 C but at station D (9 m, Cook) it was 16.4 C on the same night. Because temperature significantly affects fish distributions, (see Effects of Upwellings on Fish

Table B24. Summary of analysis of variance for spottail shiners caught in trawls at Cook Plant study areas from April through October 1973 and 1974.

Source of variation	df	Adjusted mean square[1]	F-statistic
YEAR	1	1.53407	18.40**
MONTH	6	1.25309	15.03**
AREA	1	.05549	.67
DEPTH	1	3.97830	47.72**
TIME of day	1	9.85184	118.17**
YxM	6	2.91488	34.96**
YxA	1	.05917	.71
MxA	6	.59002	7.08**
YxD	1	.53630	6.43
MxD	6	.23026	2.76
AxD	1	.09290	1.11
YxT	1	.93070	11.16*
MxT	6	3.02177	36.25**
AxT	1	.10851	1.30
DxT	1	6.54375	78.49**
YxMxA	6	.83304	9.99**
YxMxD	6	.95156	11.41**
YxAxD	1	.07753	.93
MxAxD	6	.24088	2.89
YxMxT	6	.55184	6.62**
YxAxT	1	.19427	2.33
MxAxT	6	.22424	2.69
YxDxT	1	.04967	.60
MxDxT	6	.50150	6.02**
AxDxT	1	.08050	.97
YxMxAxD	6	.15889	1.91
YxMxAxT	6	.22470	2.70
YxMxDxT	6	.49029	5.88**
YxAxDxT	1	.47933	5.75
MxAxDxT	6	.30468	3.65*
YxMxAxDxT	6	.08467	1.02
Within cell error	110[2]	.08337	

** Significant (P < .001).
* Significant (P < .01).

1 Mean squares were multiplied by harmonic cell size/maximum cell size (n_h/N = .9825) to correct for 2 missing observations where the cell mean was substituted.

2 Two degrees of freedom were subtracted to correct for 2 missing observations where the cell mean was substituted.

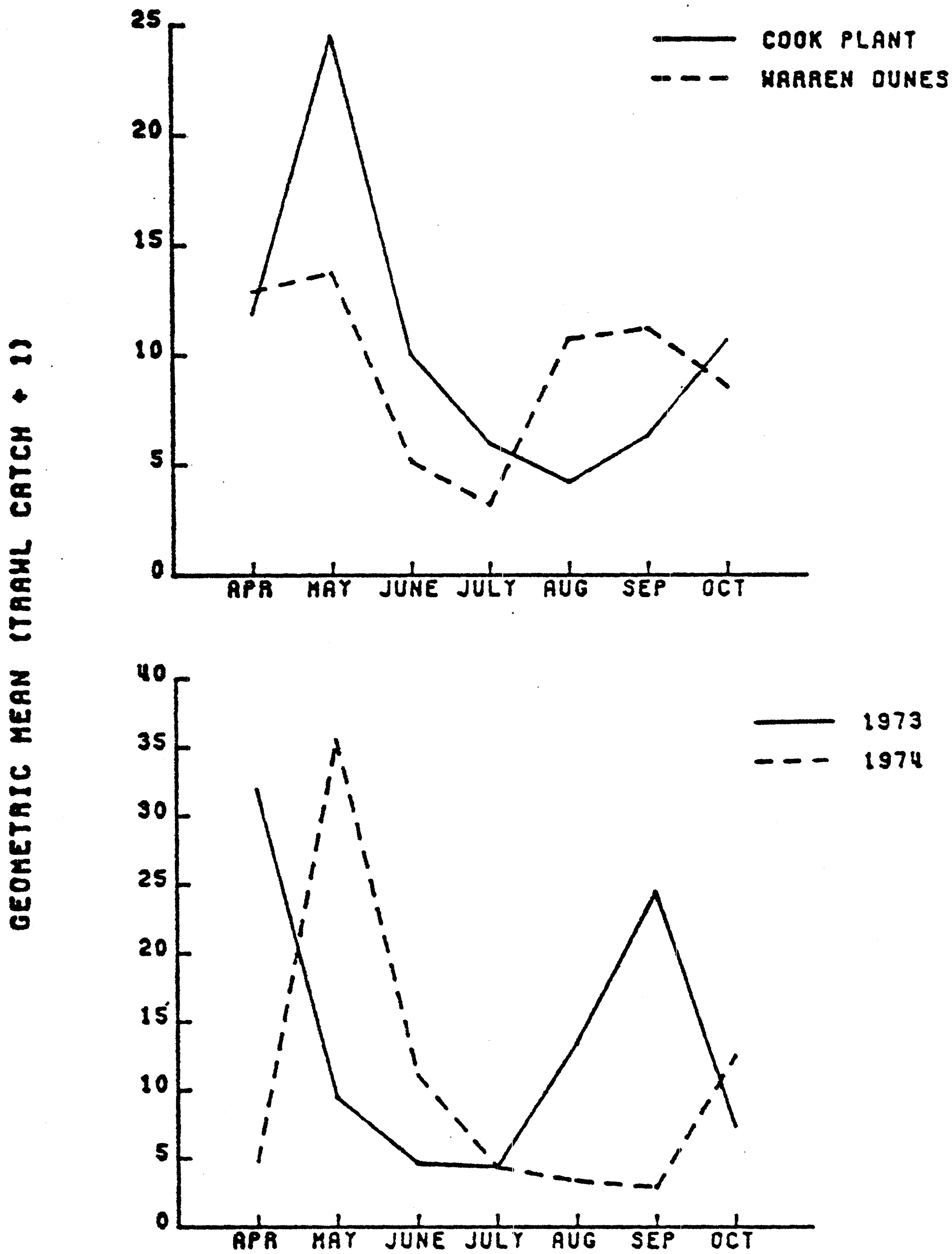


Fig. B27. Geometric mean number of spottail shiners caught in duplicate trawl hauls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

Distributions) temperature variation between stations in the same month undoubtedly contributed to the area differences in catch during August and September.

The ANOVA showed significant differences due to YEAR, MONTH, DEPTH and TIME of day, but there were also several significant interactions (Table B24). Rather than analyze each interaction separately, we will discuss some causes for the variation in relation to the biology of the species. This type of analysis will highlight the major biological activities in conjunction with physical factors which affect the distribution of spottails.

Two distinct activity patterns were found in 1973, and these were confirmed by 1974 data. These patterns involved seasonal migrations and diel movements. Seasonal migrations were found in spring and fall and appeared to follow the seasonal warming and cooling of inshore waters. These seasonal migrations were also found for several other species in the study areas (see General Diversity and Distribution of Fish Species). The spring spottail migration began in March and peaked in April 1973 or May 1974, depending on the rate of warming of the inshore waters. At this time adults and juveniles were concentrated in the trawling zones. Changes in the spring catch peak between years contributed to the significance of YEAR and MONTH and interactions of YEAR and MONTH in the ANOVA (Fig. B27). In June, July and apparently August (1974 only), the fish resided near the beach zone inside the 6-m contour, thus outside trawling depths. During August, September and October, spottails began moving offshore into trawling depths and eventually into deeper water in November. In August 1974, water temperatures were considerably below "normal" (see Fig. B6) partly due to strong upwellings. These cold temperatures apparently "forced" spottails inshore of the trawling zone (seine catches were very high). This August difference between years also contributed to the significance of YEAR and MONTH. Another part of the significance of YEAR and MONTH was the result of considerable difference in catches during September of the 2 yr (Fig. B27). The fall offshore migration activity was apparently disrupted during 1973. Again, we suspect that an upwelling caused the disruption by concentrating fish within trawling zones; under more "normal" temperatures, the fish would have been more dispersed and consequently catches lower. In contrast with the August 1974 upwelling effects, where concentrations of spottails occurred inshore of 6 m, in September 1973 the concentrations occurred within trawling zones. These extreme differences due to the intensity and month of occurrence of upwellings contributed significantly to variation in the system.

Diel movements were the second activity pattern which contributed to significance of terms in the ANOVA. High night catches at 9 m and especially 6 m in spring and fall (Fig. B28) indicated that spottails were moving inshore from deeper depths, possibly to avoid predators (seine catches were very low during the day, but high at night). Lower trawl catches during summer (especially in July) suggest that the fish were inshore of the trawling zone, probably due to spawning activities. Day catches at 6 m increased in July, possibly due to foraging after nighttime

spawning activities inshore.

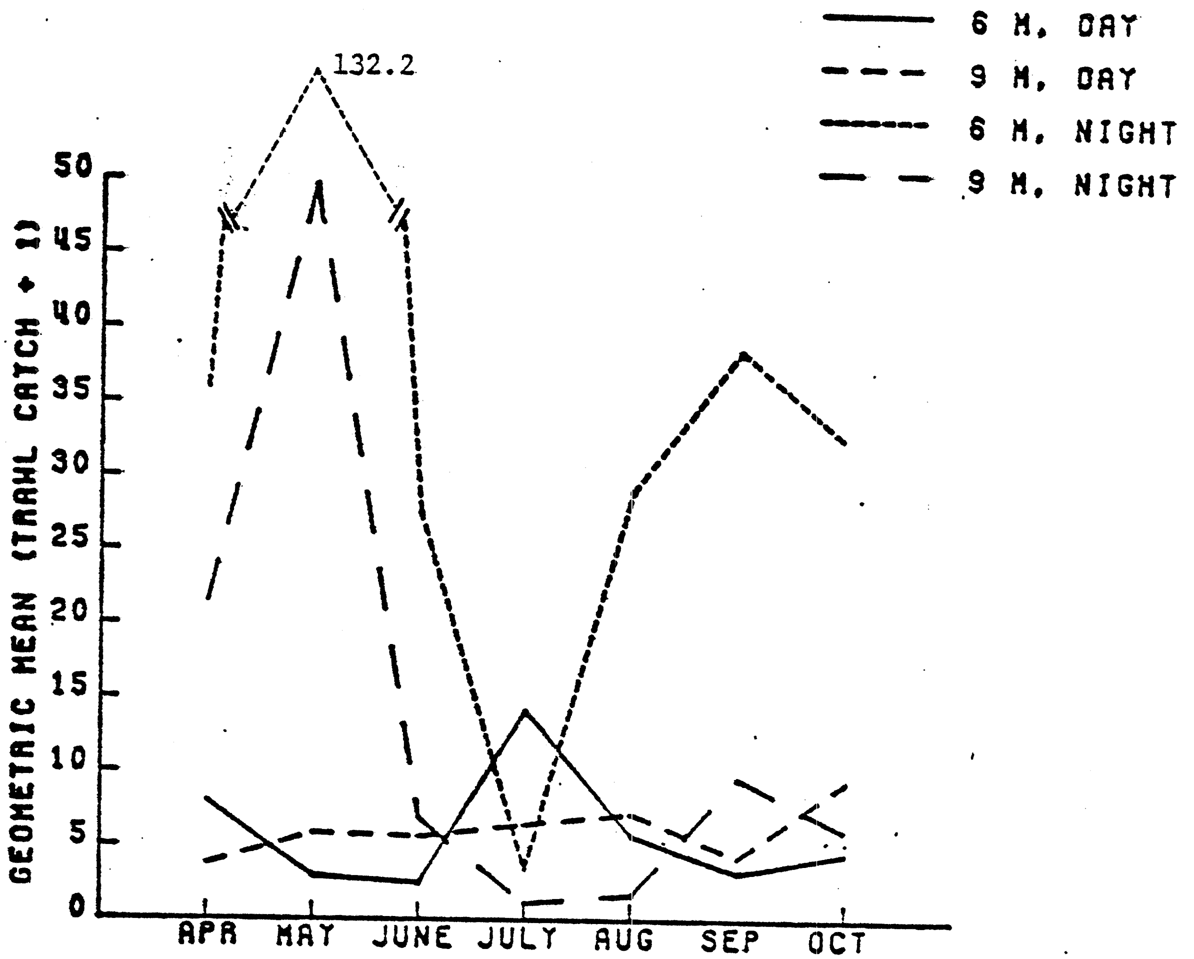


Fig. B28. Geometric mean number of spottail shiners caught in duplicate trawl hauls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

The number of significant differences in the ANOVA indicated the variability in the system. Causes for this variability were attributed to trawling methodology, size of the ecosystem and the animals themselves. Some of these causes in relation to statistical design were discussed earlier in SECTION A and also by Jude et al. (1975). Some of the major causes which affected the spottail catches will be summarized below.

Trawl samples were collected only once per month over a 1- or 2-day period, which leaves a 3- to 4-wk gap between samples. Considerable changes in distribution could occur during this time period especially during spawning months. Undoubtedly more frequent sampling, e.g., every 2 wk would

increase our knowledge of causes for monthly changes in catch, but it might also lead to overfishing of the area.

The size and nature of the Lake Michigan ecosystem causes changes in fish behavior and distribution which are responsible for the major variability in statistical inferences. Seasonal changes in weather can vary considerably from year to year. Frequency and intensity of upwellings also add to thermal variations at time of sampling. These water temperature variations not only affected monthly distribution patterns of spottails, but also changed daily movement patterns. Further, we are only sampling inshore populations of spottails from one small area of the lake; migrations from offshore and other areas of the lake can significantly change the abundance and population structure in our area.

Moderate schooling behavior by spottails, causing contagious distributions, undoubtedly added to statistical variation. There may be other unknown behavioral responses (e.g., vertical migrations) which are contributing to the variability. Nursall and Pinsent (1969) and Nursall (1973) have documented schooling behavior by spottail shiners in Beaver Lake, Alberta. Wells and House (1974) indicated that spottail shiners in Lake Erie were occasionally taken by midwater trawls.

Whatever the causes for catch variability of spottails, it is inherent to the ecosystem. This wide variability makes comparisons of population abundance and distribution between years difficult. Defining natural causes for these changes is also extremely complicated. This preoperational variability is a strong indication that it will be very difficult to statistically demonstrate any possible plant operational effects on spottail distributions and population abundance.

Gill nets -- Gill nets are only effective at catching adult spottails and therefore catches are reflective only of adult movements. Results of the ANOVA for gill net catches of spottail shiners showed significant main effects due to YEAR, MONTH and TIME (Table B25). However, all main effects entered into interactions and confounded interpretations. These interactions, like those found for trawl data statistics, are indicative of the natural variability in the system and in fish catch data.

Gill net catches demonstrated, like trawl catches, that during May and June, more fish were present at Cook than at Warren Dunes (Fig. B29). April gill net catches also showed more adults at Cook than Warren Dunes. The attractiveness of Cook to adult spottails may be the result of the riprap and underwater structures. While trawl catches declined considerably in June (see Fig. B27), gill net catches of adults were still high. Because gill nets were set for 12 h (vs. 10 min trawling time), high June catches may reflect inshore-offshore diel movements which were not shown as strongly by trawl catches. Differences in catches in August and September were possibly the result of upwellings.

Table B25. Summary of analysis of variance for spottail shiners caught in gill nets at Cook Plant study areas from March through October 1973 and 1974.

Source of variation	df	Mean square	F-statistic
YEAR	1	.87622	14.48*
MONTH	7	3.10074	51.23**
AREA	1	.17133	2.83
DEPTH	1	.02216	.37
TIME of day	1	8.67163	143.28**
YxM	7	.68130	11.26*
YxA	1	.00959	.16
MxA	7	.91711	15.15**
YxD	1	.08104	1.34
MxD	7	.76541	12.65*
AxD	1	.00550	.09
YxT	1	.60014	9.92
MxT	7	.64798	10.71*
AxT	1	.04892	.81
DxT	1	.84237	13.92*
YxMxA	7	.79137	13.08*
YxMxD	7	.33431	5.52
YxAxD	1	.00501	.08
MxAxD	7	.08393	1.39
YxMxT	7	.21217	3.51
YxAxT	1	.72511	11.98
MxAxT	7	.47801	7.90*
YxDxT	1	.00498	.08
MxDxT	7	.12936	2.14
AxDxT	1	.00138	.02
YxMxAxD	7	.06109	1.01
YxMxAxT	7	.41597	6.87
YxMxDxT	7	.31282	5.17
YxAxDxT	1	.03571	.59
MxAxDxT	7	.24690	4.08
YxMxAxDxT[1]	7	.06052	

** Significant (P < .001).
 * Significant (P < .01).

1 The YxMxAxDxT interaction is assumed to be zero and its mean square is treated as the within cell error mean square.

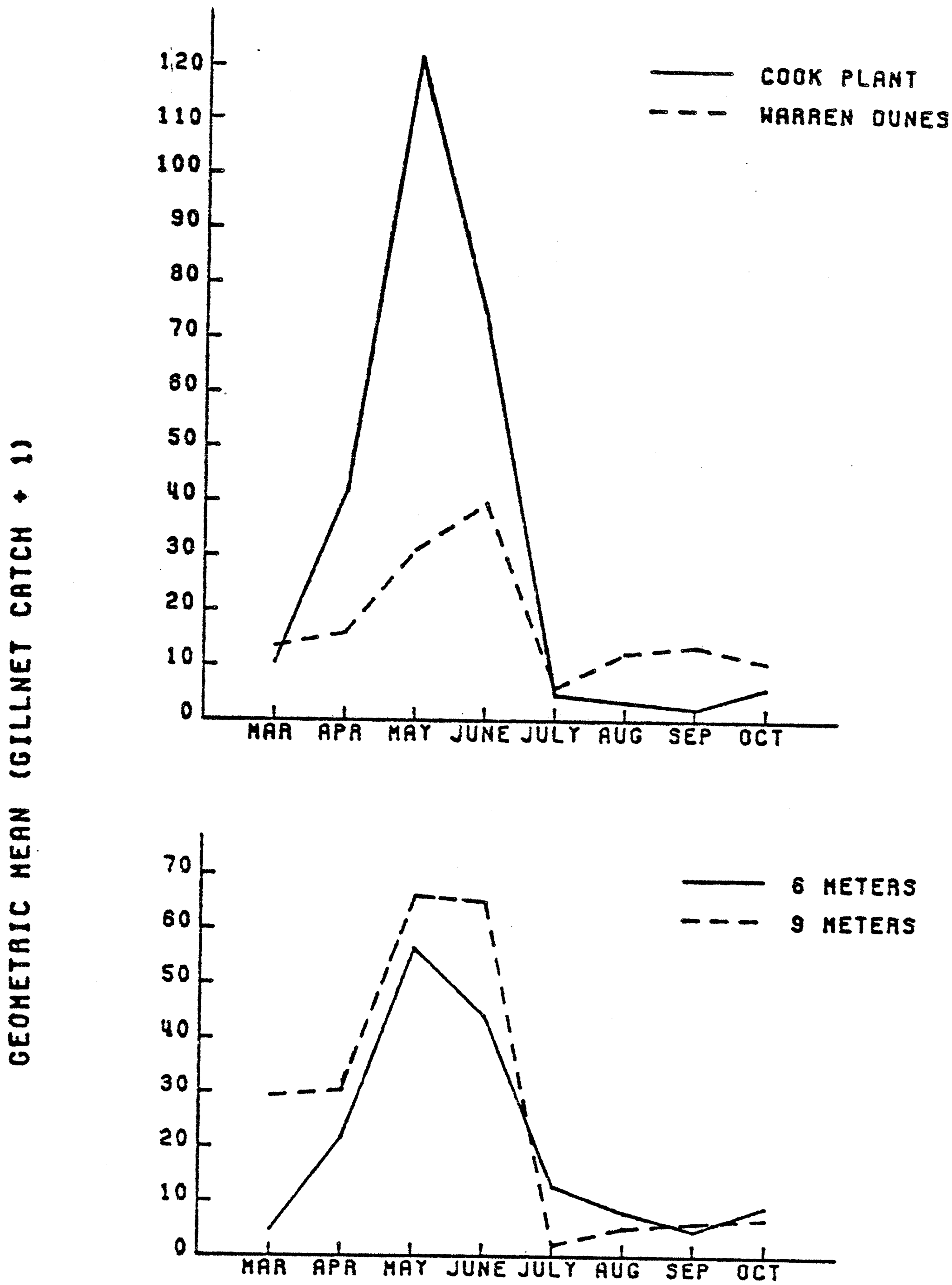


Fig. B29. Geometric mean number of spottail shiners caught in gillnets during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

Although there were no significant differences in the mean catches at 6 and 9 m, interactions including DEPTH confound clear interpretations. The MONTH x DEPTH interaction showed more adult spottails were gillnetted at 9 m than at 6 m in March and June (Fig. B29). In March, the inshore migration was beginning and adults were more abundant at 9 m. Adults may stay in deeper water at this time more than smaller fish. Wells and House (1974) found that spottails in deeper water of southeastern Lake Michigan tended to be longer and older. In June, high catches at 9 m (mostly at night) were probably related to spawning, while seine catches were high during the day and low at night. These seine catches coupled with trawl catches in June revealed all sizes of fish were inshore during the day, but at night only larger adults came into gill net depths--probably to spawn. July variation in catches at the two depths was possibly related to upwelling effects.

The YEAR x MONTH interaction can partially be explained by the spring variation in catch between years (Fig. B30). Warmer temperatures in March 1973 (see Fig. B6) apparently initiated the spring inshore migration earlier in 1973 than 1974 and accounted for the high abundance in March and April 1973. In 1974, the inshore migration was not extensive until April and into May. The difference in catches during August of the 2 yr was probably the result of an upwelling which occurred in 1973 that "forced" adult spottails from deeper depths into trawling zones.

Adult spottails were more active and abundant at night as indicated by higher night catches (Fig. B30). Nocturnal abundance was most pronounced in June (especially June 1974). As indicated above, we suspect that most spawning occurs shoreward of 6 m. But we speculate that during June 1974, sampling occurred very near the peak spawning period and the high night catches were due to nocturnal spawning or activities associated with it, occurring out to 9 m, especially by larger adults. Wells and House (1974) found most spottail shiners in southeastern Lake Michigan (off Saugatuck) were at depths from near shore to 9 m during the spawning season. They suggested that spawning was heaviest in the shallow portion of the depth range. In the present study highest night June gill net catch occurred at station D (9 m - S Cook) which is near the intake structures and riprap. These structures may be attractive to spottails for spawning habitat. Divers found spottail eggs during June of both years on and around the intake structures, and in June 1973, divers observed spottails laying eggs on the intake structure at night (Dorr 1974b, Dorr and Miller 1975).

Again it must be emphasized that gill net data, like trawl data, are variable. Due to natural fluctuations in monthly temperature, upwellings, long periods between samples, contagious fish distributions, gear bias and sampling methodology, there are considerable causes for data variation between months and years. With this extent of variation, it will be very difficult to detect plant discharge effects on spottail distribution and abundance.

Seines -- Results of the ANOVA for seine catches of spottail shiners revealed significant main effects due to MONTH and TIME (Table B26).

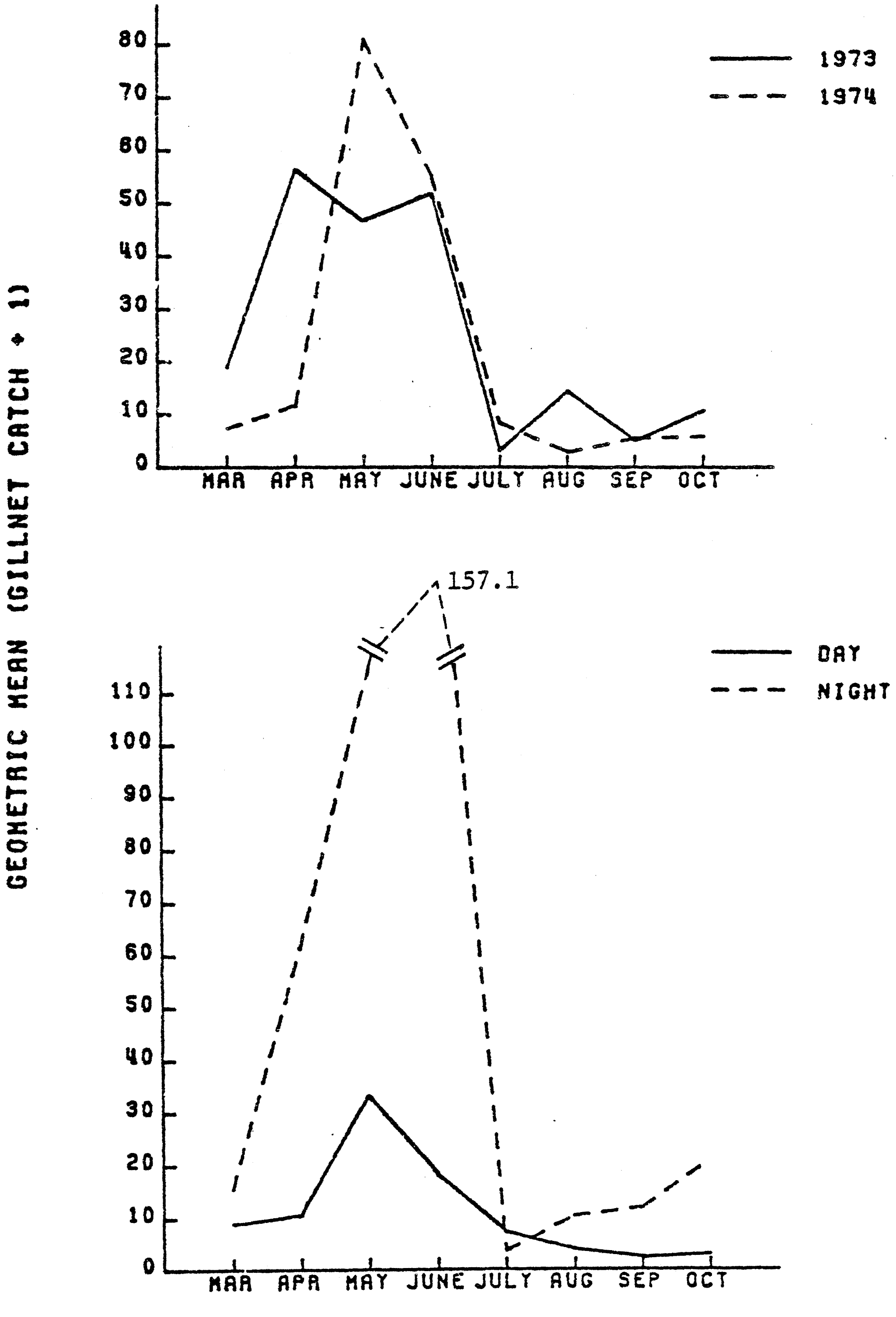


Fig. B30. Geometric mean number of spottail shiners caught in gill nets during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

Differences in catch between STATIONS and YEARS were not significant. However, these statistical findings have to be weighed against significant interaction effects of all main factors (except STATION) in the ANOVA test. Again, like the trawl and gill net data, significant interactions in the ANOVA were indicative of the high variability in spottail catches. Definable biological and physical factors which contributed to this variability are discussed below.

Table B26. Summary of analysis of variance for spottail shiners caught in seines at Cook Plant study areas from April through October 1973 and 1974.

Source of variation	df	Adjusted mean square[1]	F-statistic
YEAR	1	.45835	1.72
MONTH	6	9.21090	34.52**
STATION	2	.91677	3.44
TIME of day	1	2.07137	7.76*
YxM	6	2.99669	11.23**
YxS	2	.10578	.40
MxS	12	.43731	1.64
YxT	1	.21387	.80
MxT	6	2.67611	10.30**
SxT	2	.94020	3.52
YxMxS	12	.36641	1.37
YxMxT	6	2.92424	10.96**
YxSxT	2	.19272	.72
MxSxT	12	.41786	1.57
YxMxSxT	12	.62689	2.35
Within cell error	83[2]	.26680	

** Significant ($P < .001$).
* Significant ($P < .01$).

1 Mean squares were multiplied by harmonic cell size/maximum cell size ($n_h/N = .9882$) to correct for 1 missing observation where the cell mean was substituted.

2 One degree of freedom was subtracted to correct for 1 missing observation where the cell mean was substituted.

While no significant difference was found between the 1973 mean catch and the 1974 mean catch, some monthly catches were quite different between years. A higher 1973 May catch and higher catches in summer 1974 contributed to the interaction of MONTH with YEAR (Fig. B31). The greater May 1973 catch was evidently the result of warmer spring temperatures in 1973 compared to 1974 (see General Distribution and Diversity of Fish Species). These warmer temperatures caused the spring inshore migration to occur earlier in 1973. This spring variation was also noted for trawl and gill net catches, and alewife and trout-perch catches (see Alewife and Trout-perch sections).

Causes for the high summer 1974 abundance, as evidenced by large seine catches (Fig. B31), are difficult to define. Two possible reasons are a population increase or a distribution change as a result of thermal dissimilarities between years. We believe the local population increased as a result of good spawning success in 1973. This large year class appeared as YOY in 1973, and again as yearlings during summer 1974 (more discussion follows under Comparisons of 1973 and 1974 distributions by age-size class). While large numbers of yearlings increased the summer 1974 seine catches, summer temperature variations between years also caused a distribution change which affected catch sizes. Average water temperatures for June, July and August 1974 were 3.0, 1.5 and 3.2 C lower than respective months in 1973 (see Fig. B6). We believe the cooler temperatures caused spottails to concentrate in the beach zone to a greater extent in 1974 than in 1973. Spottails apparently preferred warmer temperatures and in 1973 they had available more area of warm temperature. In 1974, cooler temperatures caused them to concentrate in the beach zone where water temperatures were the warmest.

Although mean catches at the three beach stations for the 2 yr pooled were not significantly different, some differences among station catches were noted. As in 1973, (Fig. B15 in Jude et al. 1975), 1974 June day catches at station B (S Cook) were considerably higher than at stations A (N Cook) and F (Dunes) (Fig. B32). Catches during July and August 1974 were also very large. We suspect the attractiveness of station B (S Cook) to spottails during summer was a result of physical characteristics of this station. During 1973, a temporary harbor built of sheet piling and rock rubble was in existence 0.2 km north of station B. This structure afforded some wave protection and rocky habitat not present at beach stations A and F. In early 1974, the harbor was removed, but considerable amounts of scrap iron, concrete reinforcing steel bars and rock rubble were left behind. These materials added to the uniqueness of station B by affording fish an irregular physical habitat not present at the sandy flat bottom typical of other stations and areas of the southeastern shore.

Mean day and night seine catches were significantly different (Table B26). A trend first found in 1973 data and again observed in 1974, was predominantly nocturnal abundance in spring and higher catches during the day in summer (Fig. B31). We suspect that in spring spottails were deeper than 9 m feeding. At night they returned to the warmer shallow beach water

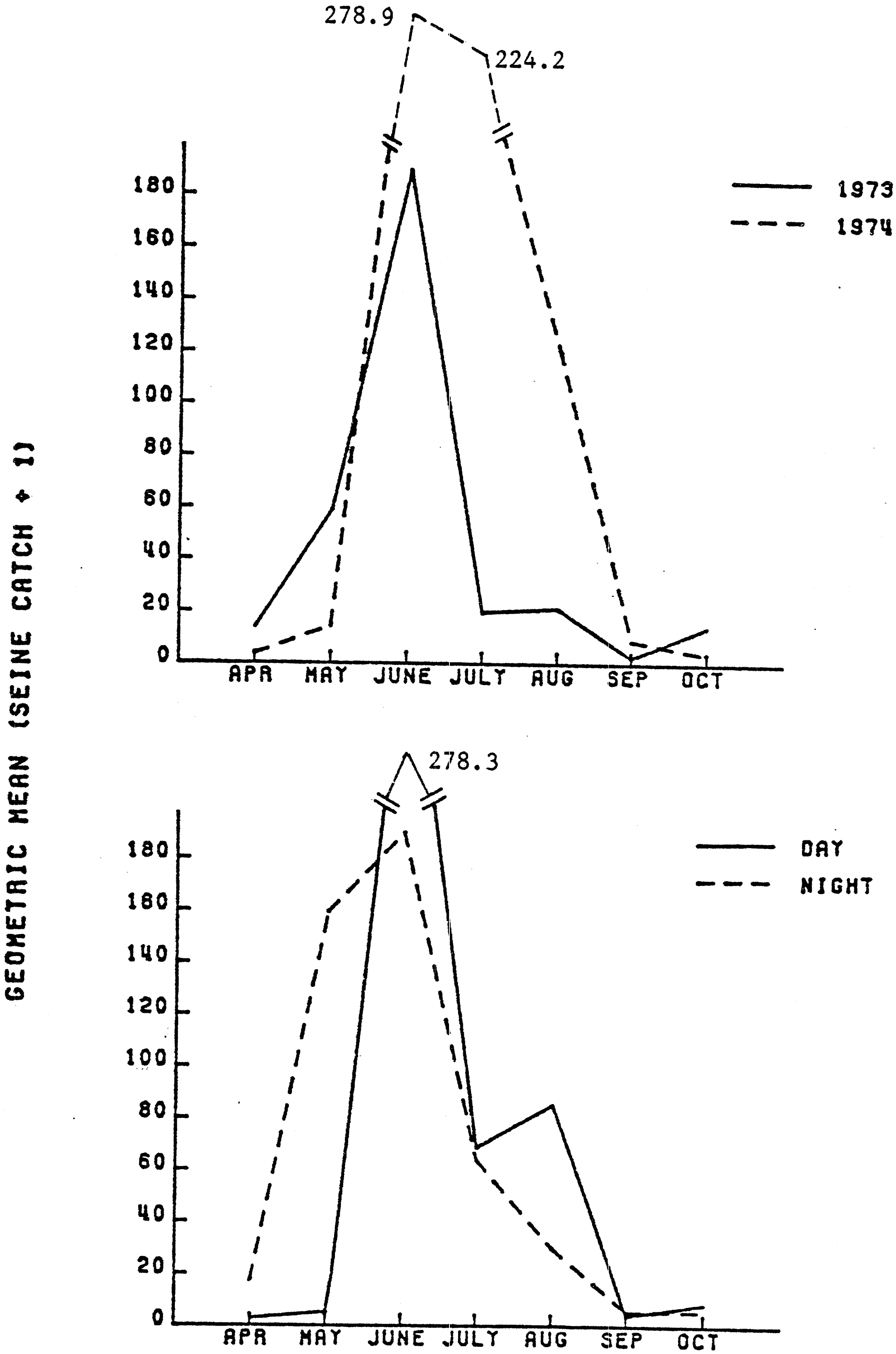


Fig. B31. Geometric mean numbers of spottail shiners caught in seines during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

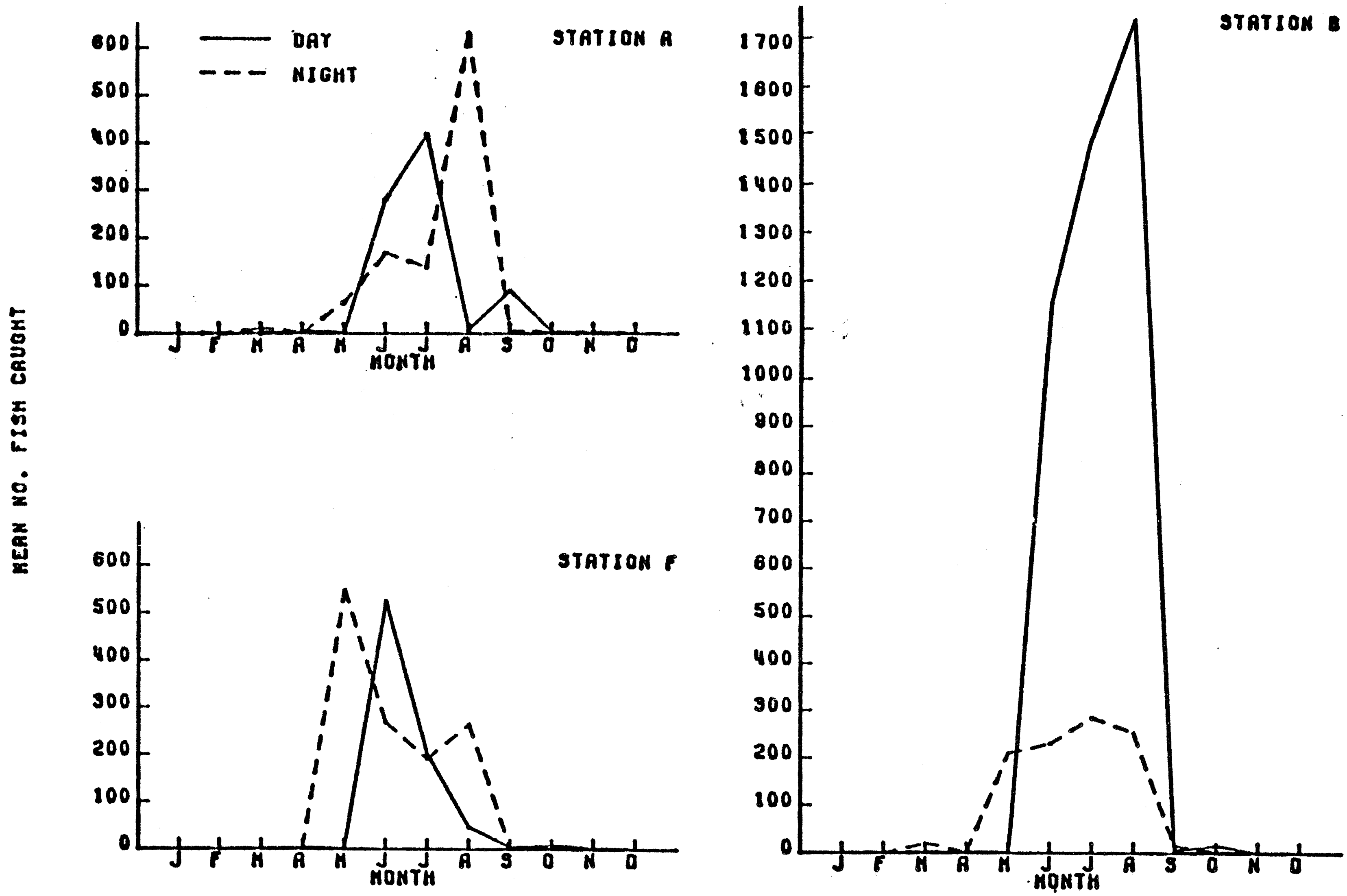


Fig. B32. Mean number of spottail shiners caught day and night in standard series seines during 1974 at station A (N Cook), station B (S Cook) and station F (Warren Dunes), southeastern Lake Michigan.

which was probably a preferred habitat offering some protection from predators. This suspicion is quite tenuous and may be substantiated by future stomach content analysis. Peak summer catches, with day catches higher than night catches, were a result of the population concentrating to spawn. Apparently at night numbers decrease as some of the ripe fish leave the beach zone to spawn in deeper (>1.5 m) water.

Like gill net and trawl catches, seine catches of spottails were quite variable. We can define some causes for this variability, but some reasons are still unknown.

Seasonal distribution by age-size class -- Length-frequency histograms of spottails caught in standard series nets were compiled by gear type (Figs. B33 - B35). Because we did not age spottails, only three life stages--YOY, juveniles or yearlings and adults can be delineated from the standard series length-frequency data. This section will discuss seasonal distribution of age-size classes caught in 1974, followed by a comparison of 1973 and 1974 data.

Young-of-the-year -- Young-of-the-year (YOY), 15-44 mm, were first caught by beach seines in August 1974 (Fig. B33). These catches lent support to a June and July spawning period in the study area. Spawning dates for Lake Michigan spottail shiners from other studies were June to July (Basch 1968), June to August (Wells and House 1974), mid-June to early July (Jude et al. 1975). As Wells and House (1974) indicated, spawning season varies from year to year depending on water temperatures. Spawning times reported in the literature for other areas were early May (McCann 1959) and late May to early June (Griswold 1963) in Clear Lake, Iowa; July (second week) in Nemeiben Lake, Saskatchewan (Peer 1966); July (second week) in Red Lakes, Minnesota (Smith and Kramer 1964); June in the Kalamazoo River, Michigan (Wells and House 1974); late June to early July (Fish 1932) and early June to mid-July (Wells and House 1974) in Lake Erie. Some spottail larvae (see SECTION C) were collected by us in June 1974, but peak catches occurred in July, again adding evidence to June-July spawning. Plankton net collections revealed that spottail larvae were demersal (like adults) and stayed in very shallow depths, from 1.5 m to shore. Seine and trawl data (YOY were not collected by trawling until October, Fig. B35) revealed that YOY also stayed in shallow water.

In September, YOY had grown to 25-54 mm (Fig. B33), while in October, the length interval increased to 25-64 mm. The broad size range of YOY, plus larvae collection data (see SECTION C) denote a prolonged spawning period of at least 2 mo for spottails . Seined YOY were taken primarily during the day. Evidently YOY leave the beach zone at night, probably foraging for food. During October, YOY had left the beach zone entirely, but were still present at trawling depths. After October, most YOY had moved from our sampling area into deeper water with adults and juveniles.

Yearlings -- Yearling is a more proper term than juvenile for 1-yr-old spottails because some fish mature at 1-yr old (Wells and House 1974).

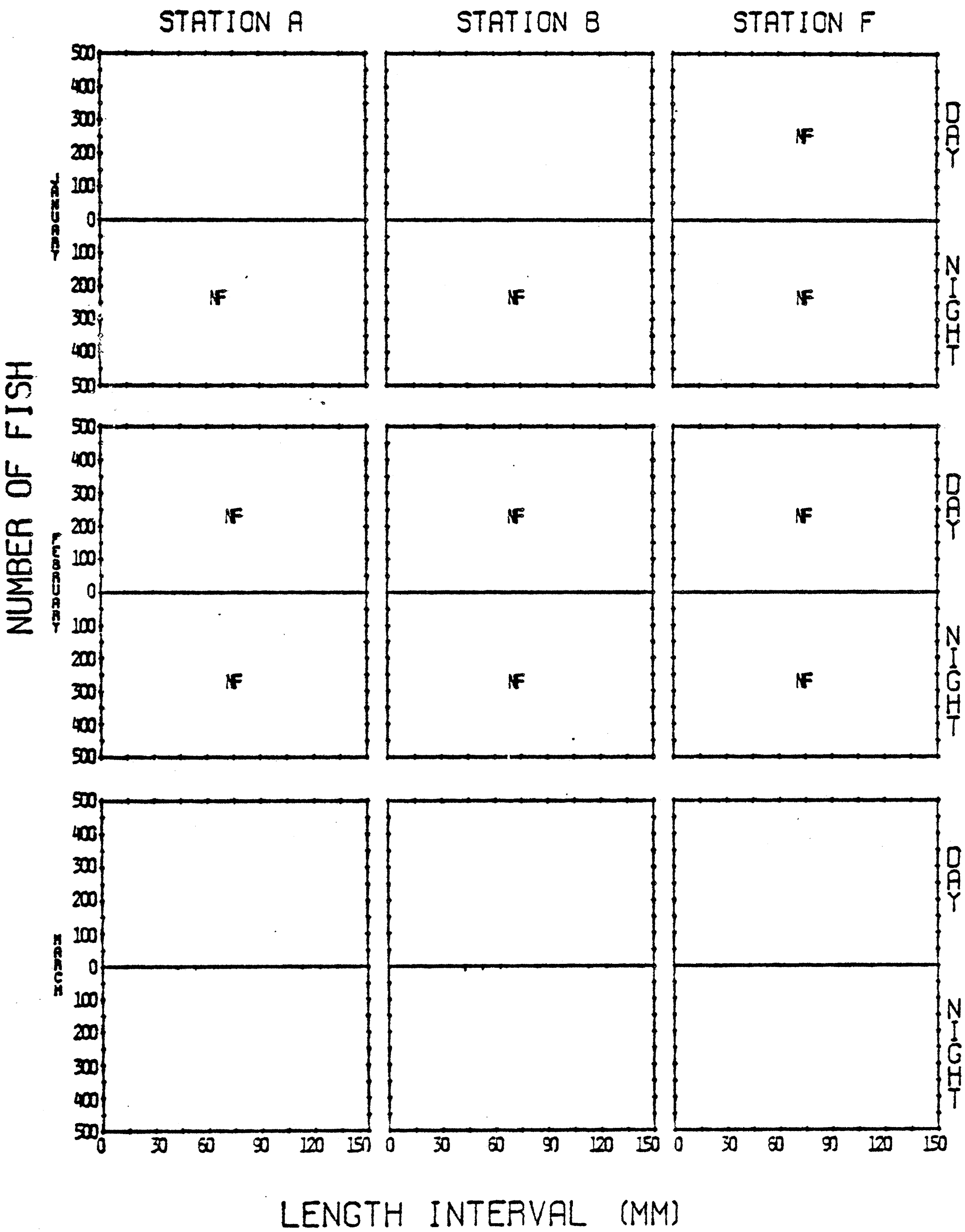


Fig. B33. Length-frequency histograms for spottail shiners caught by standard series seining during 1974 at Cook Plant study areas, southeastern Lake Michigan. NF = not fished.

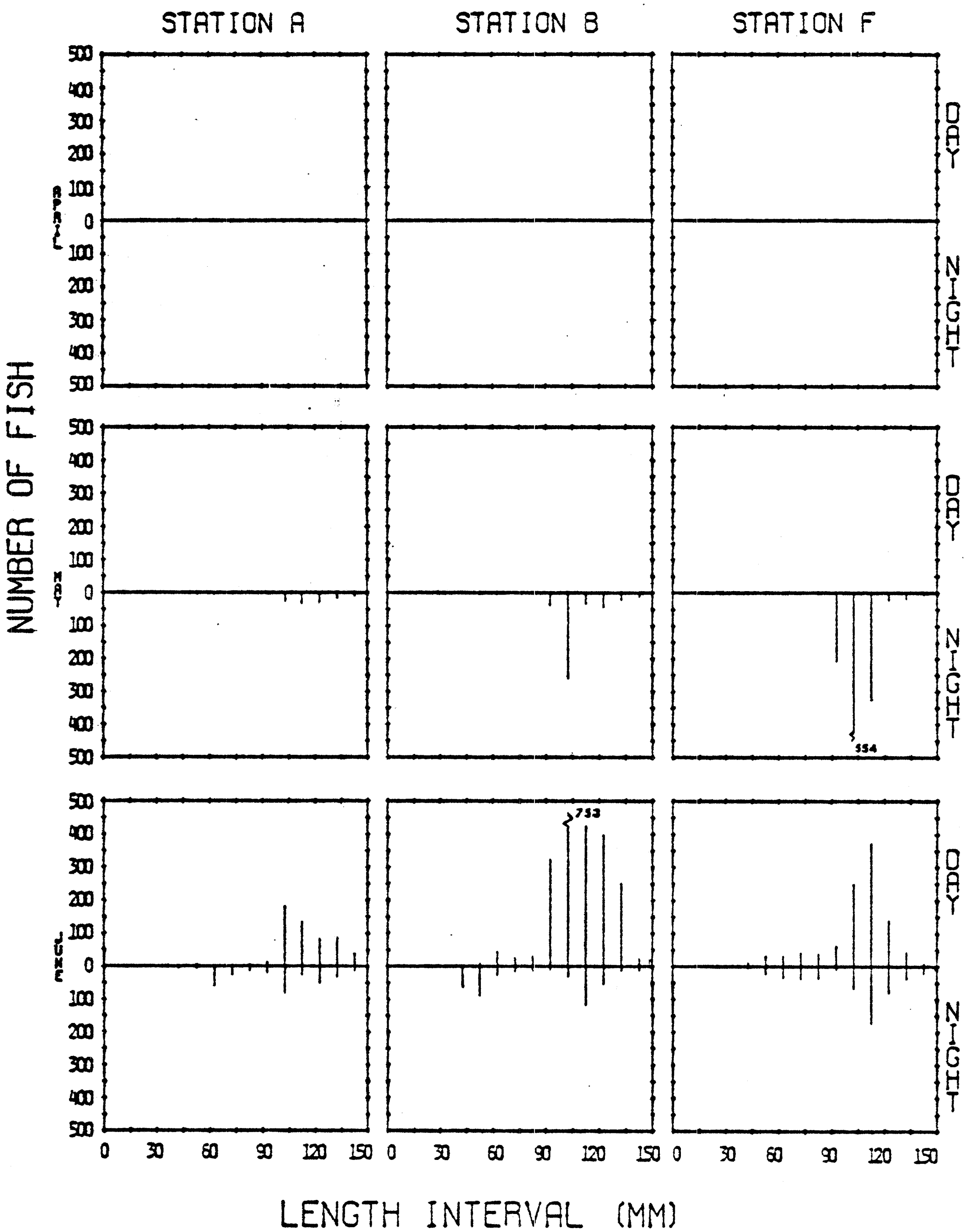
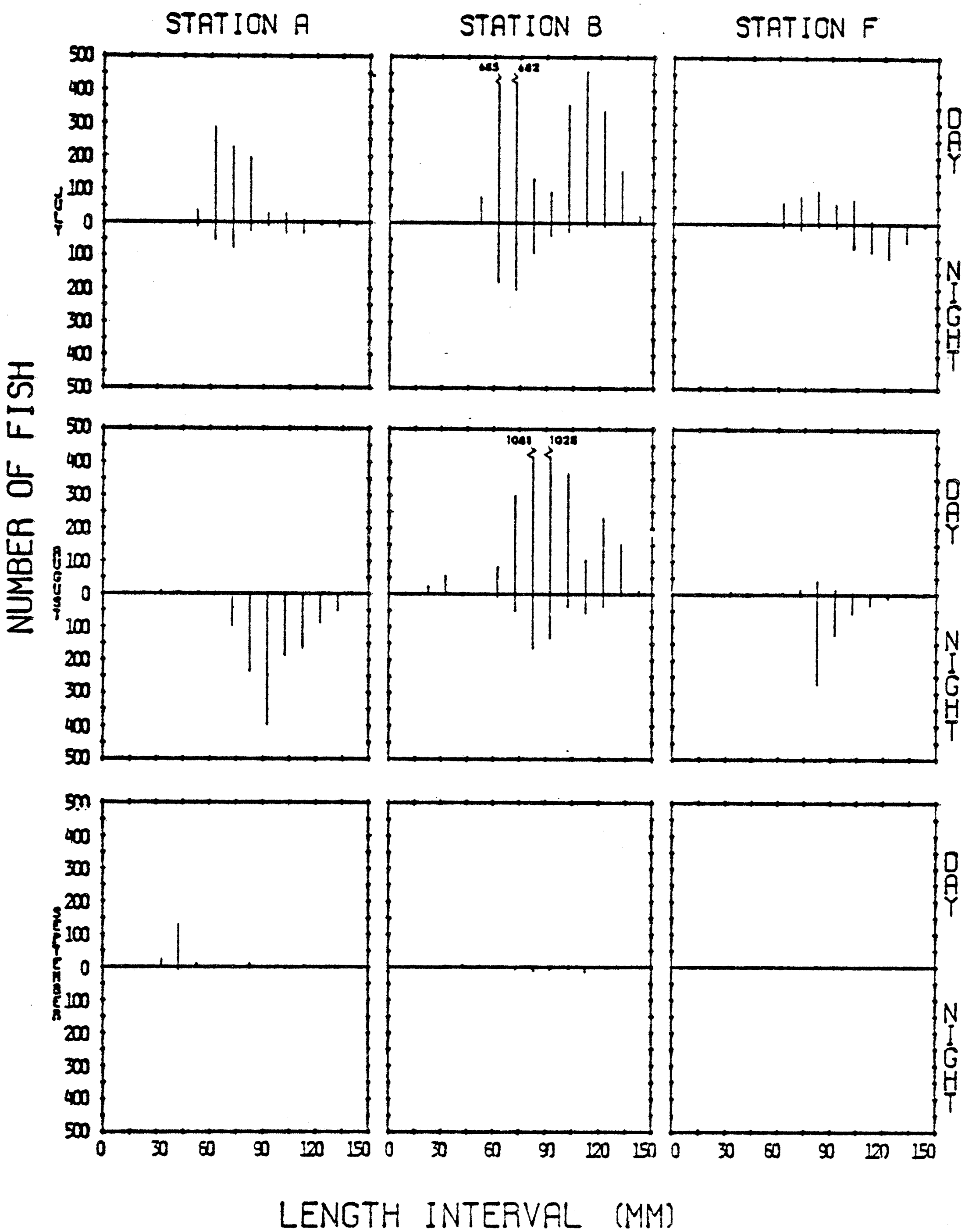


Fig. B33. Continued.



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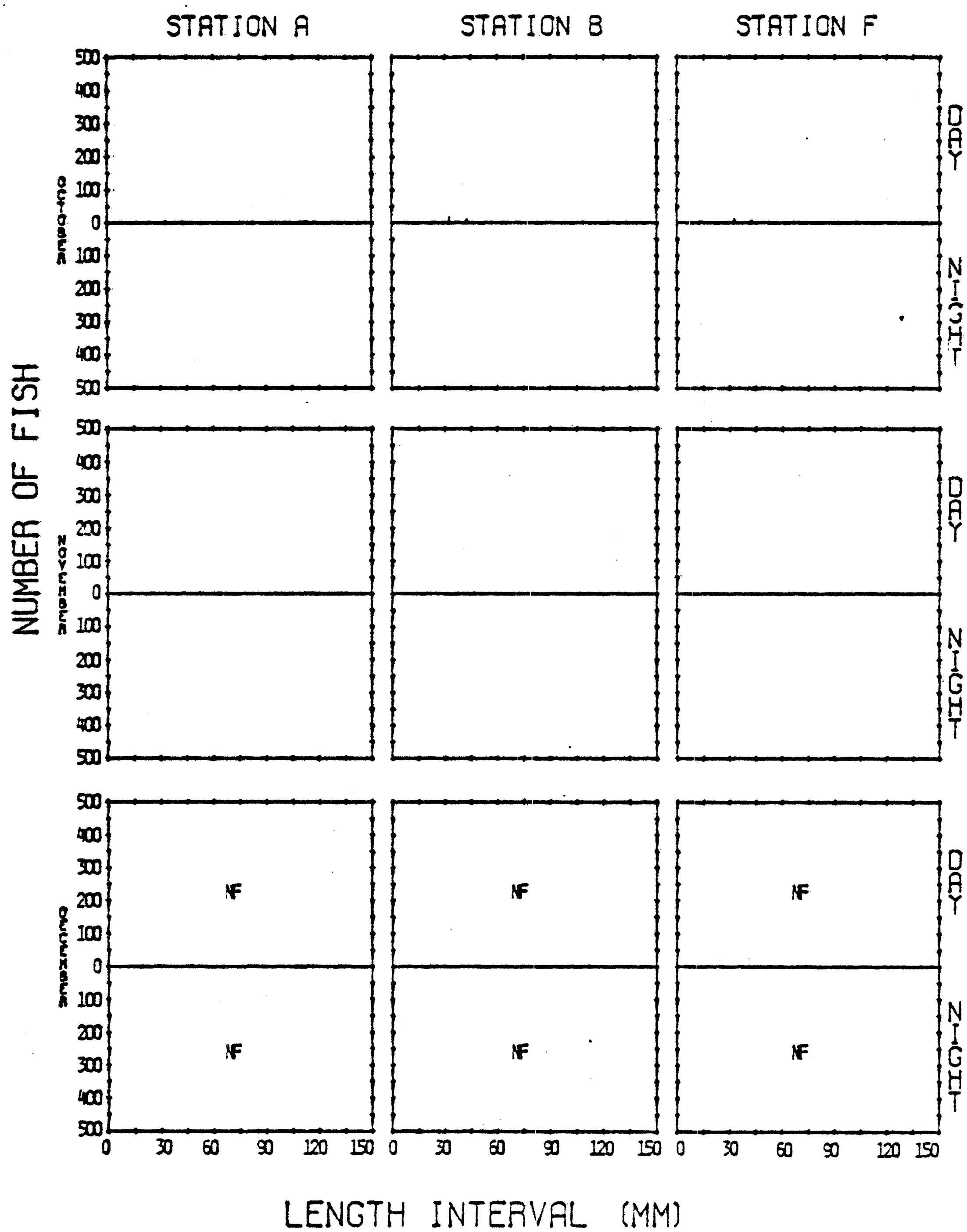

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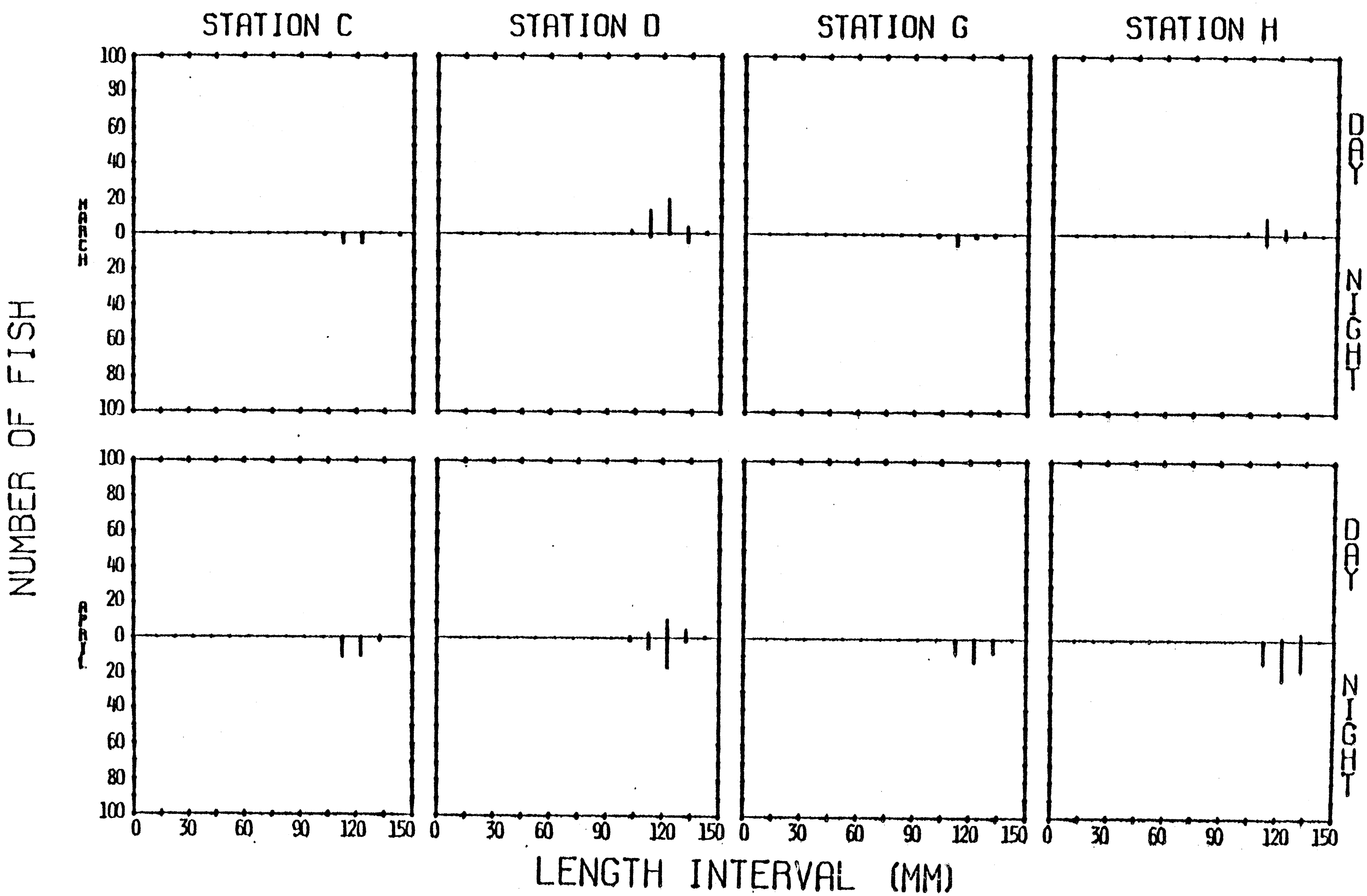
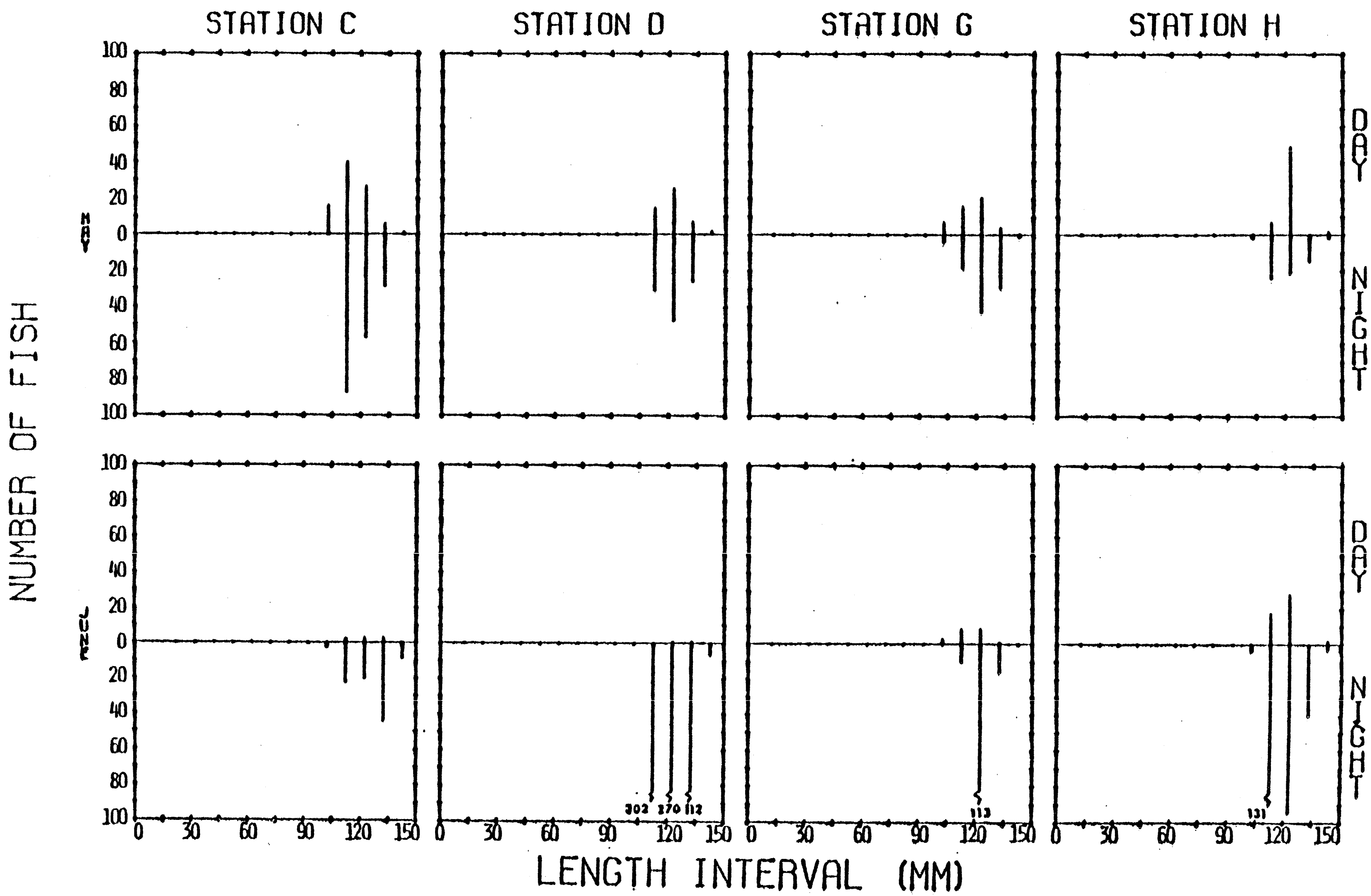


Fig. B34. Length-frequency histograms for spottail shiners caught by standard series gillnetting during 1974 at Cook Plant study areas, southeastern Lake Michigan.



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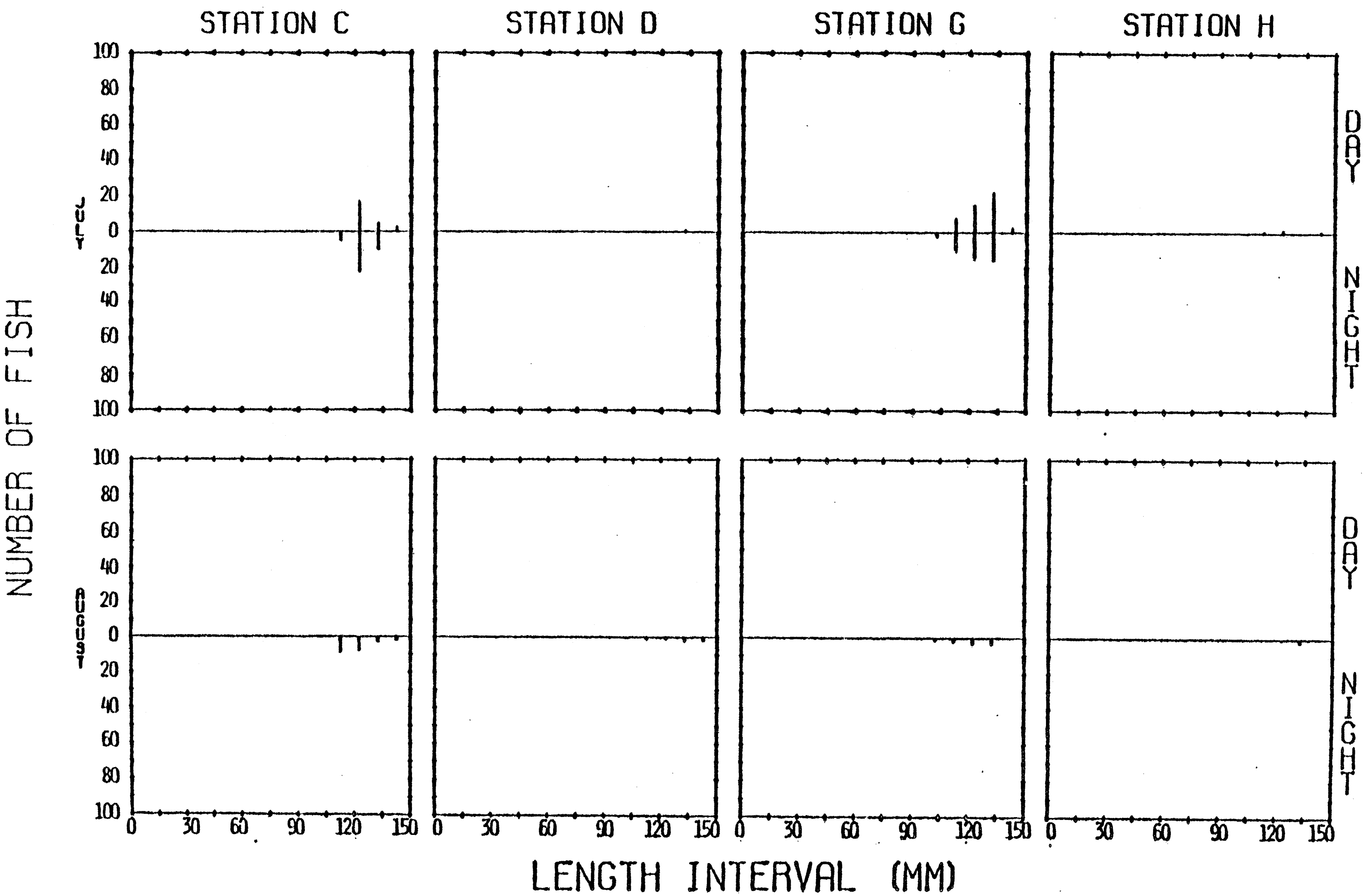

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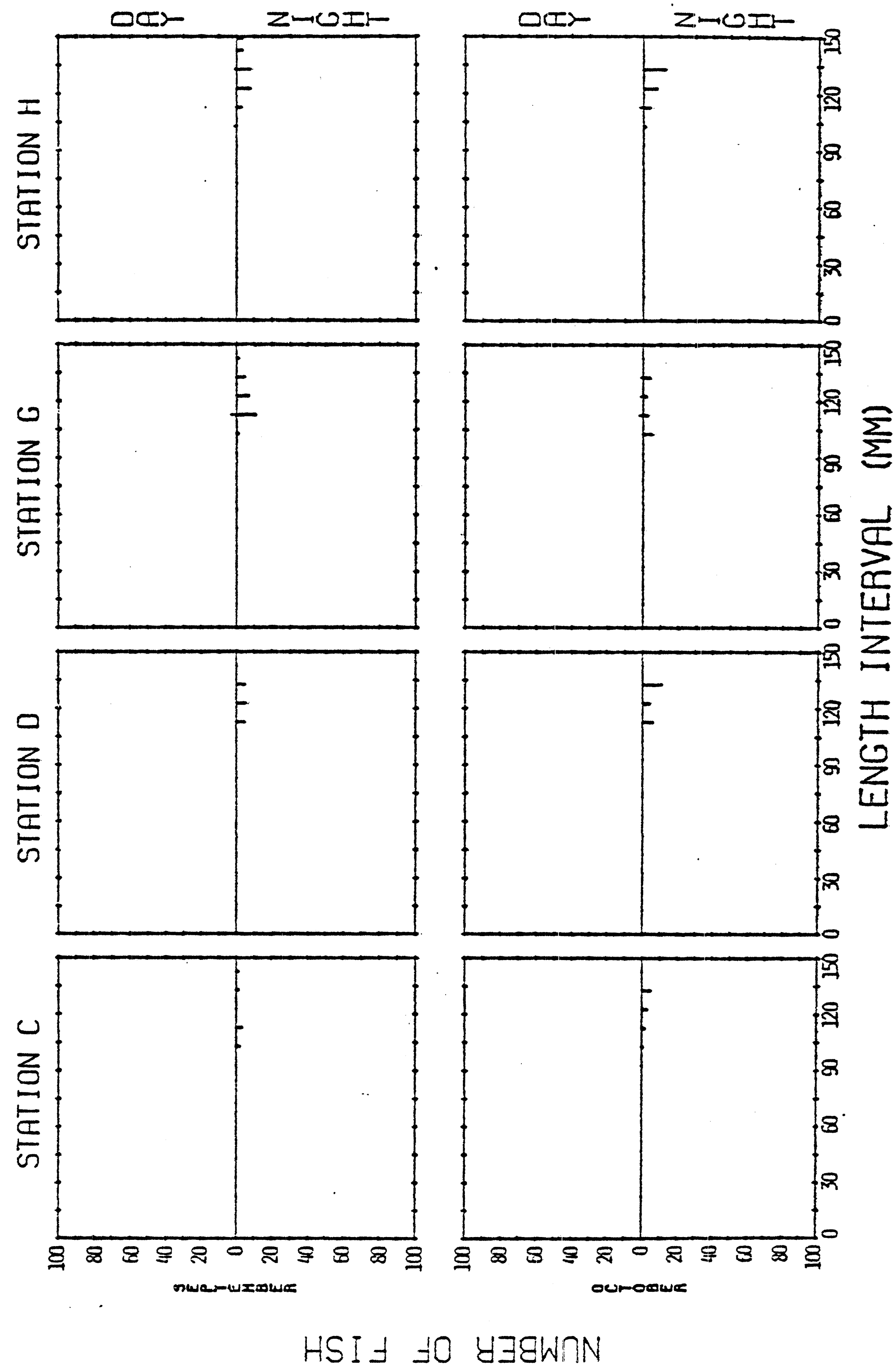

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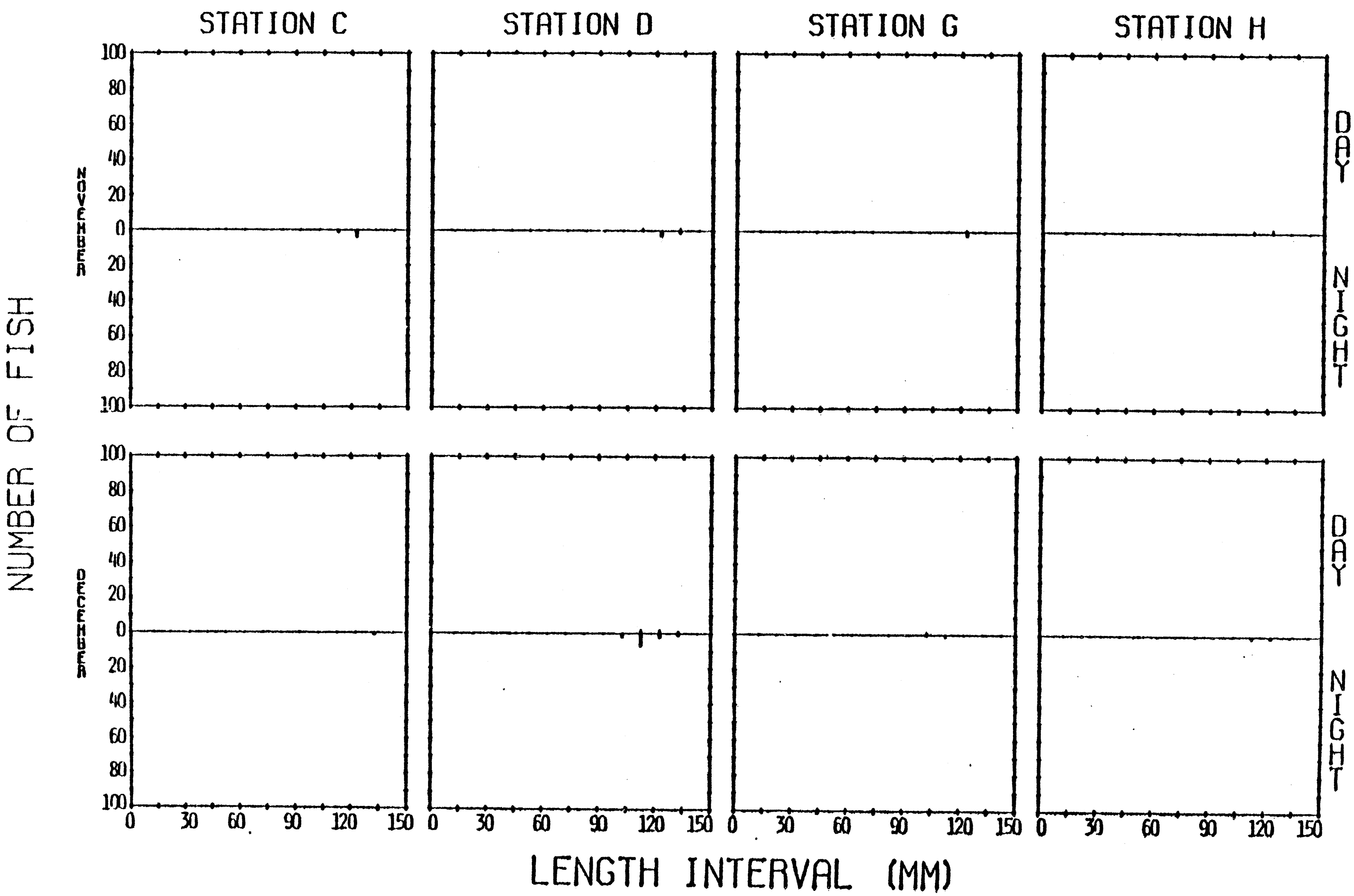

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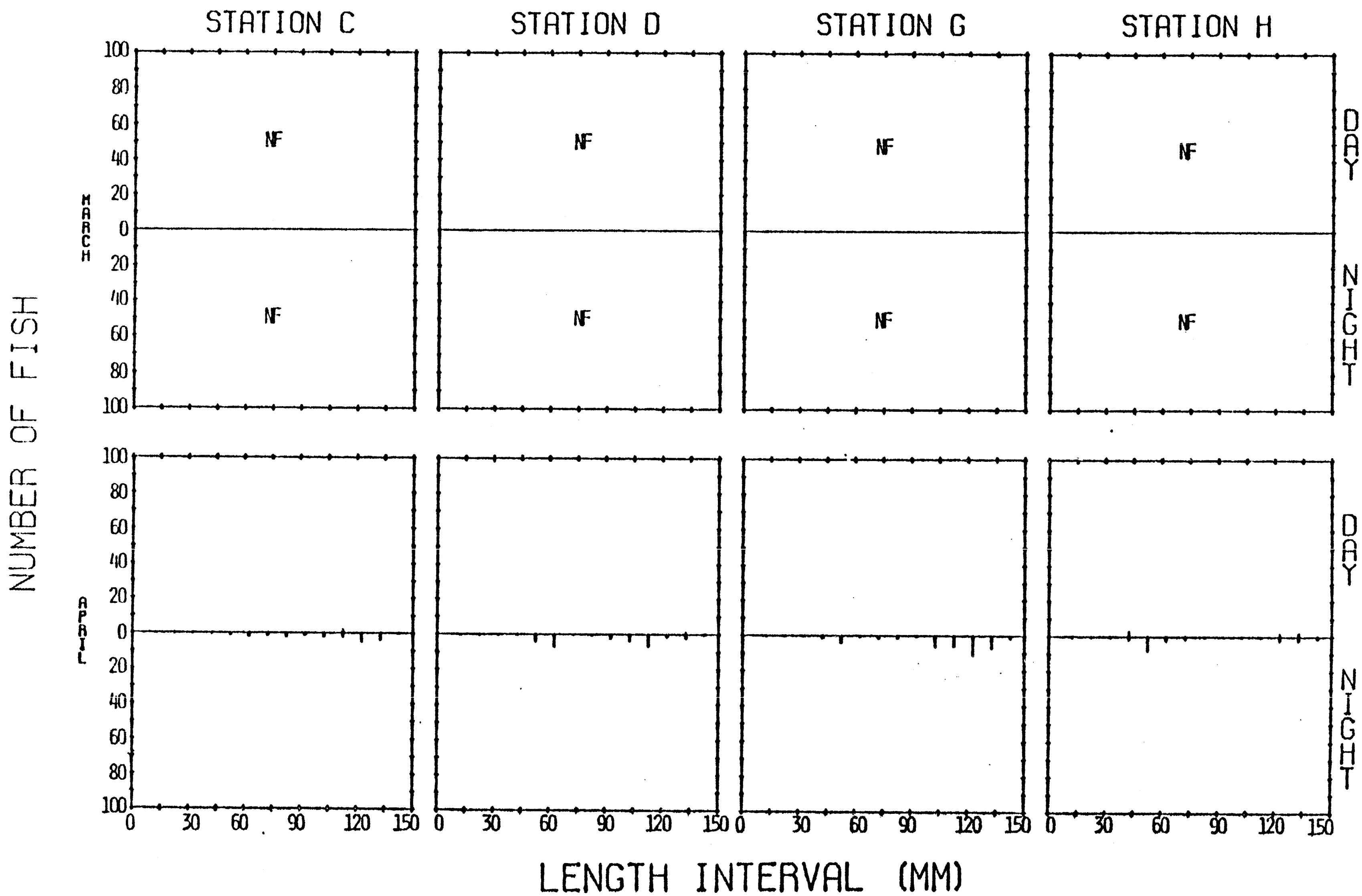


Fig. B35. Length-frequency histograms for spottail shiners caught by standard series trawling during 1974 at Cook Plant study areas, southeastern Lake Michigan. NF = not fished.

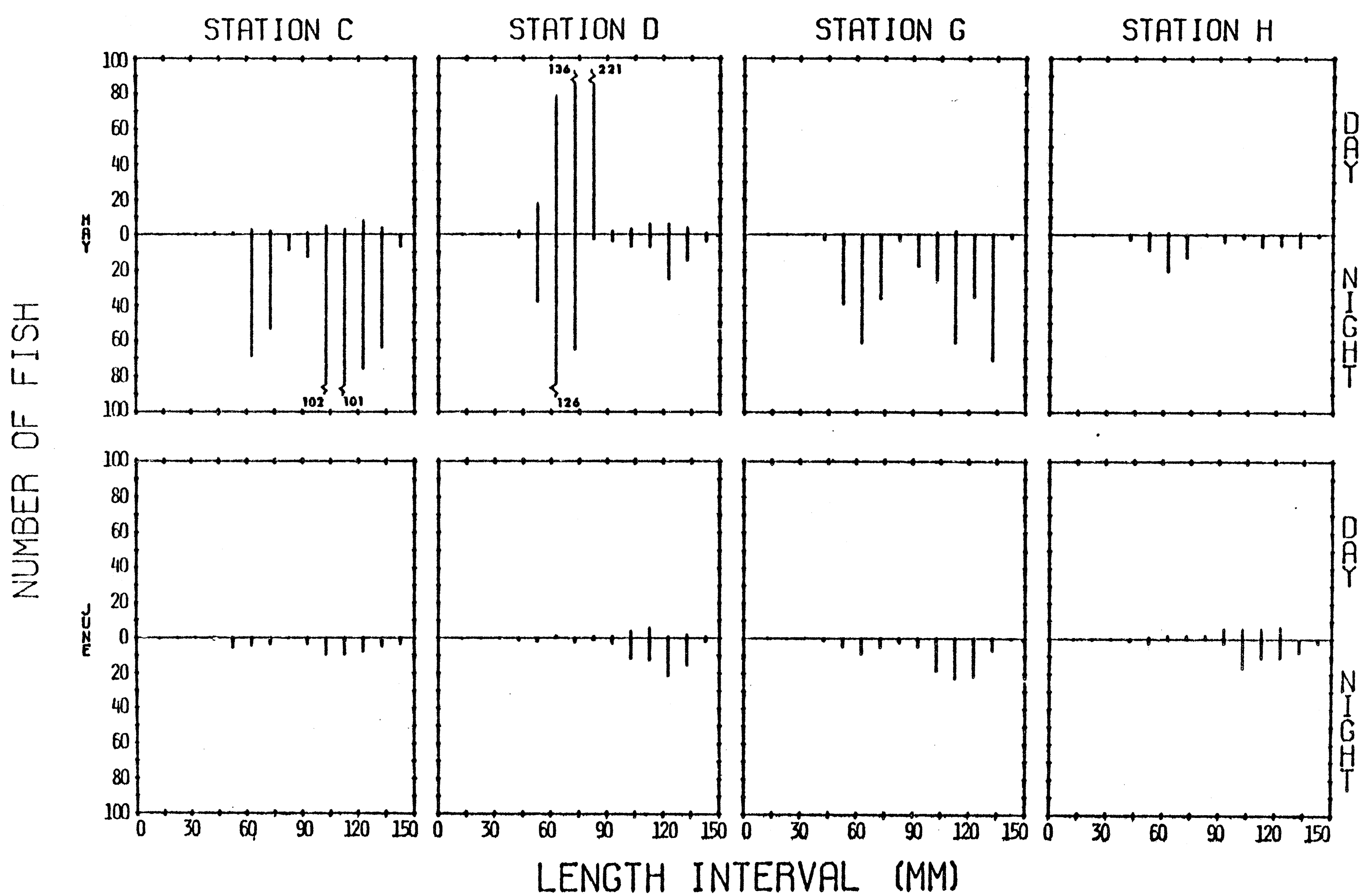


Fig. B35. Continued.

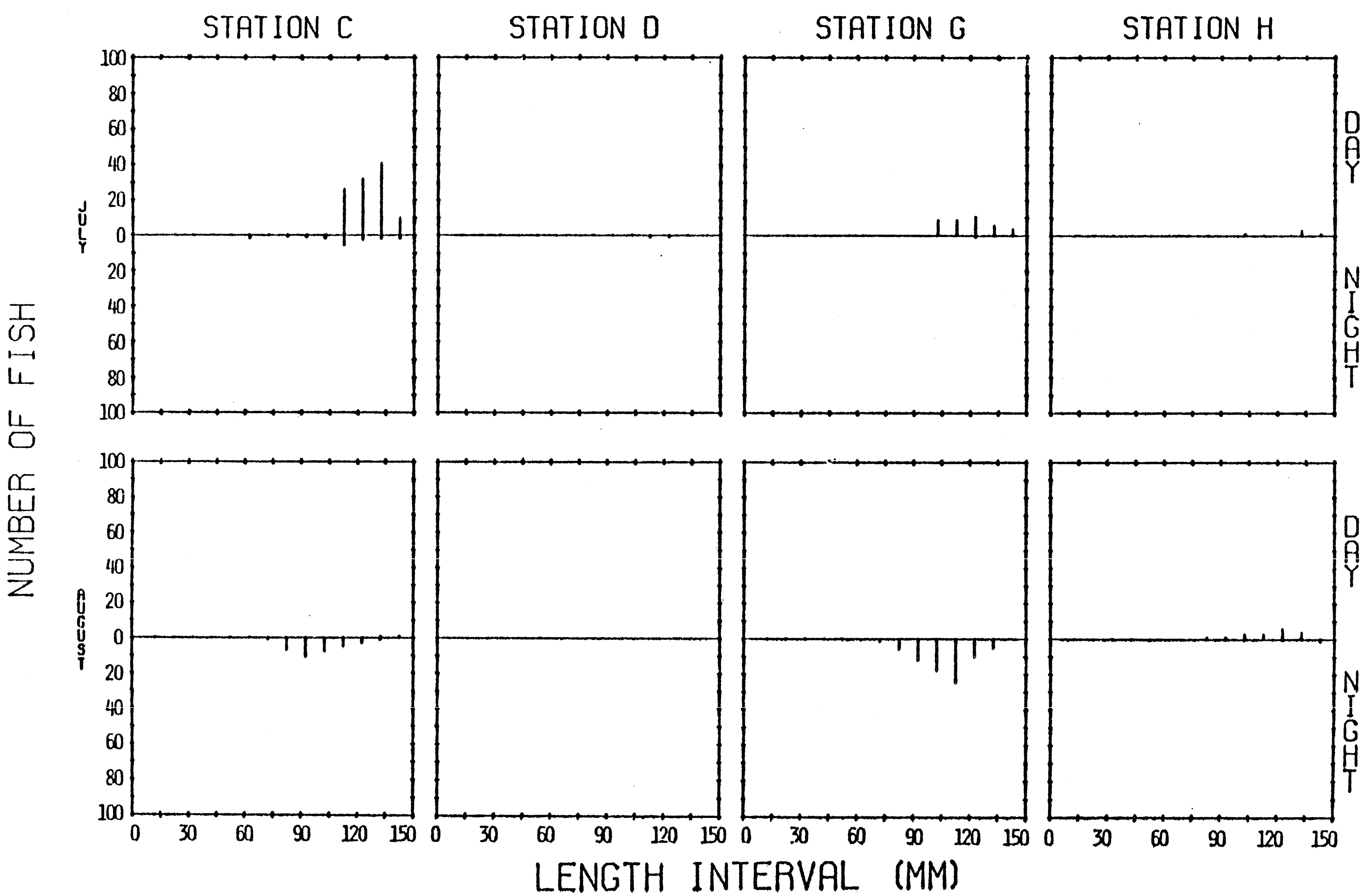


Fig. B35. Continued.

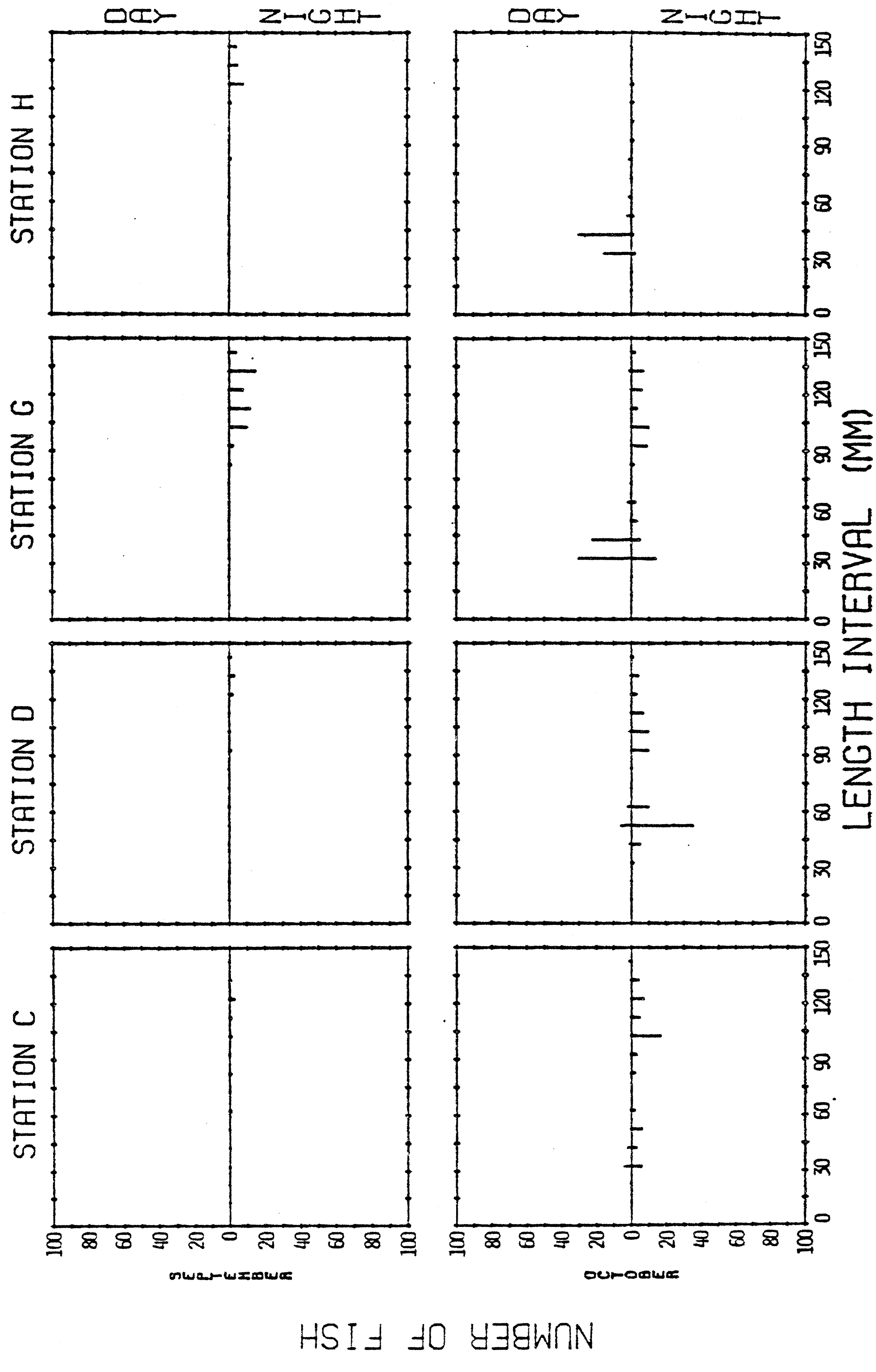


Fig. B35. Continued.

Yearlings were caught in appreciable numbers in May (Fig. B35). A few were seined in March and a few trawled in April. In April, yearlings were 35 to approximately 74 mm. Fishes of this size range were caught into June, indicating that very little growth occurred in spring. Wells and House (1974) found spottail growth did not begin until June in southeastern Lake Michigan. No juveniles under 45 mm were caught in July which suggests that considerable growth occurred in June and July. By August, juveniles could not be distinguished from smaller adults in length-frequency plots.

Adults -- Adults were caught throughout the entire sampling period, but abundance varied considerably between sampling depths. Size of most adults caught in March and April was 105-134 mm. Age data of Wells and House (1974) would indicate these adults to be 3- to 5-yr old. Gill net catches in March revealed adults moving to at least 6 m at night and out to 9 m and beyond during the day (Fig. B34). In April, nocturnal catches predominated at both depths, but day catches were still high at 9 m.

Major influx of adults occurred in May and June, and again, most were in the 105-134-mm size range with some also 135-154 mm. Catches indicated most activity at 6 and 9 m was nocturnal. The first influx of adults in the beach zone occurred in May and peaked in June (Fig. B33). Activity was nocturnal in May, but shifted to diurnal in June. Apparently spottails moved into the beach zone (<1.5 m) from 6 and 9 m at night. In June, adults stayed in the beach zone during the day probably because of spawning activities. On June 13 and 26, divers found spottails eggs on the intake cribs off the plant, adding conclusive evidence of spottails spawning in the study area (Dorr and Miller 1975).

During July and August, catches of adults in the 105-134-mm size range declined, probably due to post-spawning mortality and migrations out of the area. Peer (1966) found mature spottail shiners left sandy shoals immediately after spawning in Nemeiben Lake, Saskatchewan. Very few adults were caught in the beach zone after August in southeastern Lake Michigan. However, trawl and gill net catches revealed that some adults were still present at 6 and 9 m.

Other studies (Smith and Kramer 1964, Basch 1968 and Wells and House 1974) have found females growing to larger sizes than males. Our data also revealed that larger fish were predominantly females. In 1973, out of all fish greater than 120 mm captured, 90% were females; in 1974, 93% were females. Largest spottail caught in 1973 was a 152-mm (37.8 g) female, largest caught in 1974 was a 152-mm (29.0 g) female.

Comparisons of 1973 and 1974 distributions by age-size class -- To facilitate age-size class comparisons between years, monthly length-frequency histograms were compiled for all spottails collected in 1973 and 1974 (Figs. B36 and B37). Because of unequal fishing efforts between years (see Fishing Effort), actual numbers cannot be accurately compared between years.

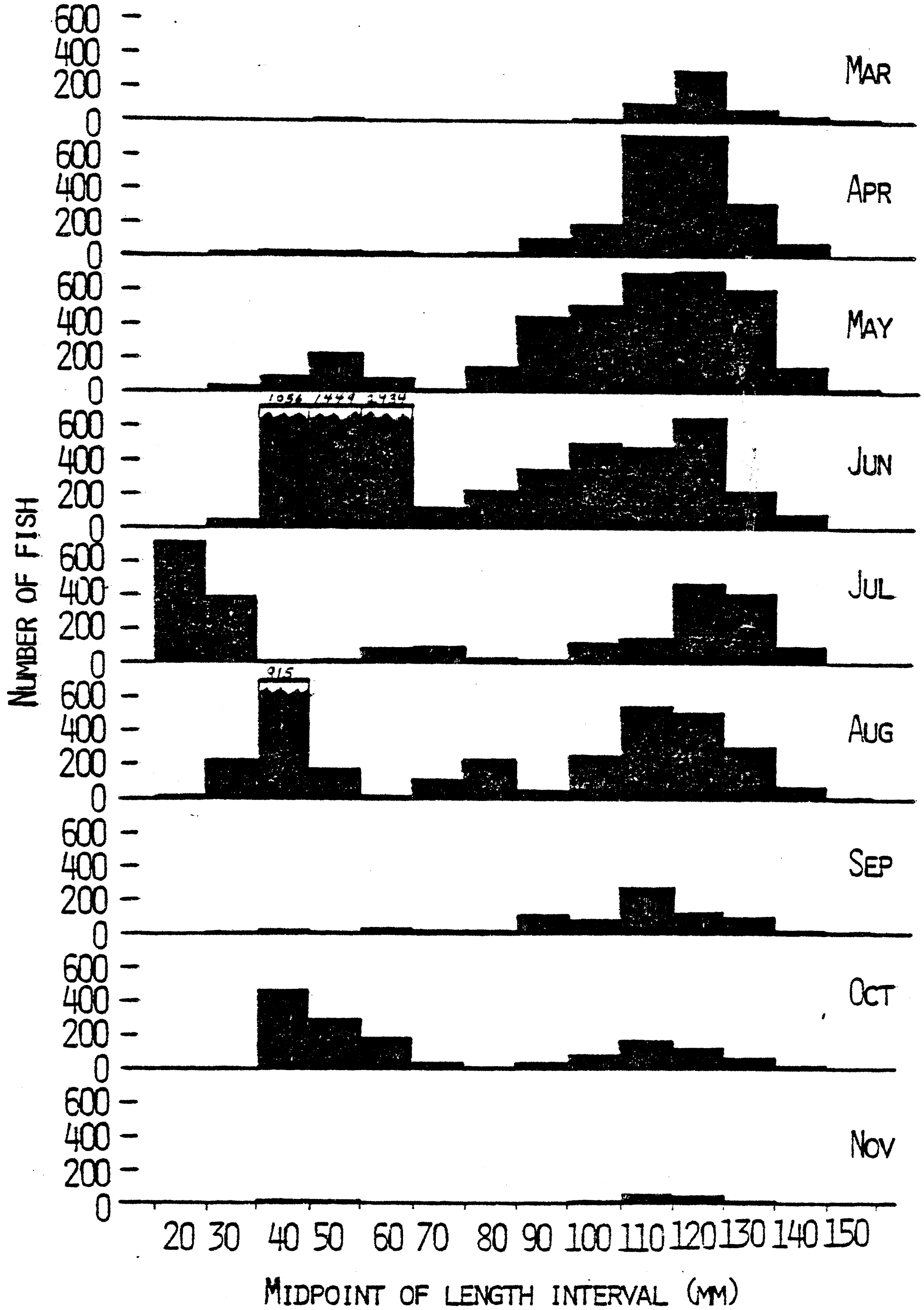


Fig. B36. Composite monthly length-frequency histogram of all spottail shiners collected during 1973 at Cook Plant study areas, southeastern Lake Michigan.

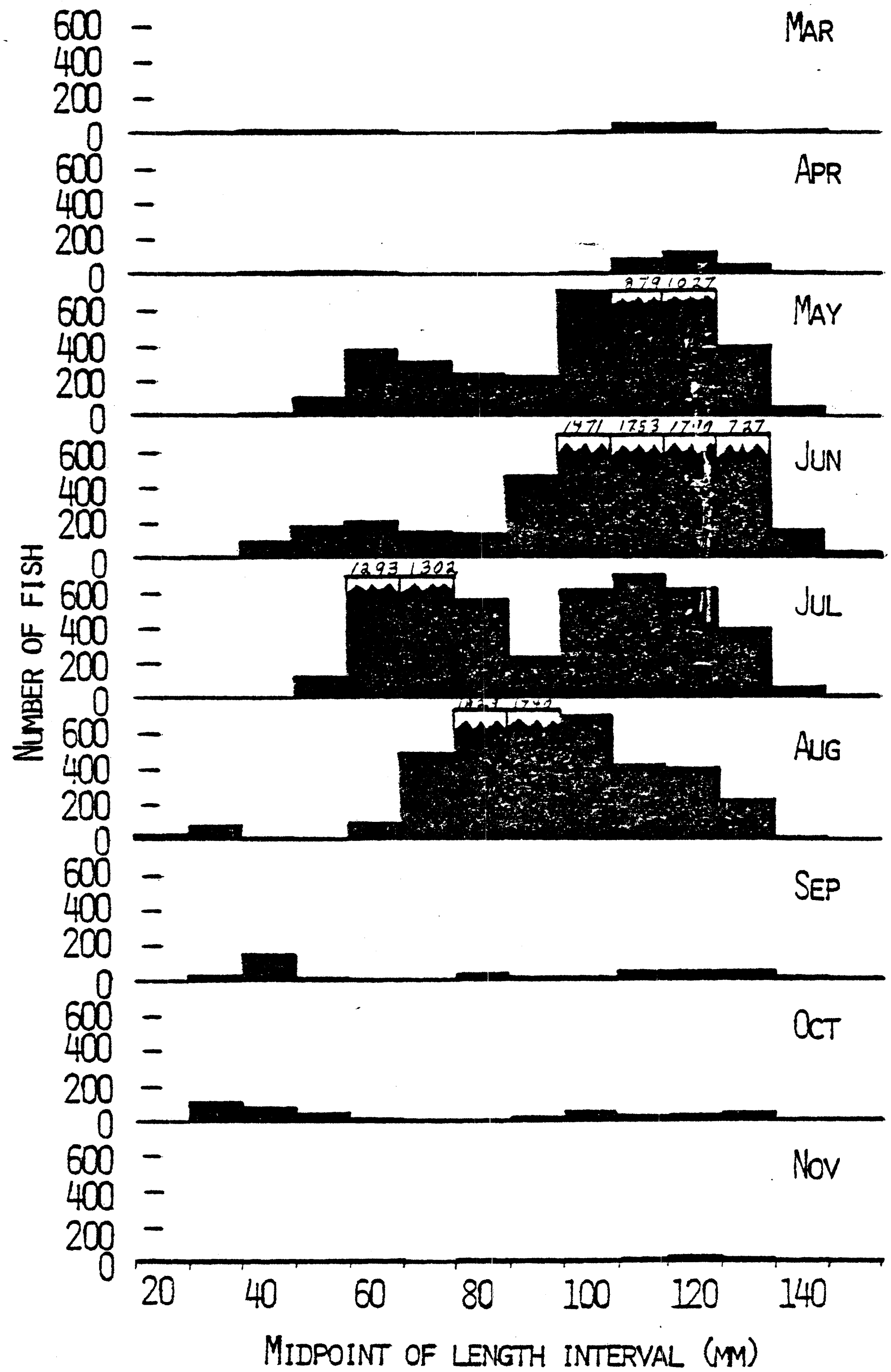


Fig. B37. Composite monthly length-frequency histogram of all spottail shiners collected during 1974 at Cook Plant study areas, southeastern Lake Michigan.

In 1973, considerable numbers of YOY were caught in July, but in 1974, YOY were not caught until August (Figs. B36 and B37). This would suggest that spawning probably occurred earlier in 1973 and spawning success was considerably greater than in 1974 in the study areas. Except for September, when high waves were encountered during seining, more YOY were caught in summer and fall months of 1973 than in 1974, again showing better spawning success in 1973. The cause for this better success in 1973 may be related to water temperatures in June. Average water temperature for June 1973 was approximately 3 C above the 20-yr norm and the June 1974 average temperature (see Fig. B6). Average July 1973 water temperature was also above the 20-yr norm and the July 1974 average temperature. Evidently, the warm temperatures and fair weather conditions in summer 1973 were conducive to spottails spawning in the study area.

The early and better spawning success appears to have given the 1973 year-class a growth advantage. At least YOY growth was better in 1973 than in 1974. In October 1974, YOY were 25-64 mm, whereas in October 1973, they were 35-74 mm (Figs. B36 and B37). The 1973 year class also appeared as 35-74-mm yearlings in May 1974. Added evidence to 1973 being a good year for YOY growth was that yearlings of the 1972 year-class were 25-64 mm in May 1973 (Fig. B36). The large 1973 year class also appeared in 1974 as large numbers of yearlings in May, June, July and August catches. Comparing yearling catches in 1973 and 1974 showed (except for June 1973) considerably more yearlings caught in May, July and August 1974.

As indicated in the 1973 report (p. 103 and Table B17 in Jude et al. 1975), our YOY in 1973 grew noticeably slower than was found in other studies. In 1974 YOY showed an even slower growth than in 1973 which demonstrated further the considerable difference in growth between southeastern Lake Michigan spottails and those in other habitats. We believe the slow growth of YOY is partially the result of competition with YOY alewives for food since both species are concentrated inshore during late summer and fall.

Temperature-catch relationships -- Spottail shiners were caught over the full range of water temperatures encountered while sampling in the study areas (Fig. B38). These data revealed that at least some fish were present in the study area through the year. The majority (74%) of the total standard series catch of spottails was taken in temperatures above 17.9 C indicating the fish probably prefer warm temperatures. Wells (1968) found spottails in southeastern Lake Michigan were in water from 13 C to the warmest available. A considerable portion (49%) of our catch was taken at the highest temperatures encountered (24-27 C). These fish were caught by seining and demonstrate the spottail's preference for very shallow warm waters in the study area.

Our catch data revealed large spottails were caught in cooler temperatures than smaller fish (Fig. B39). Adults (110-154 mm) were collected in water between 17 and 22 C and YOY (15-64 mm) between 23 and 26 C. These data showed a definite temperature preference change with length of

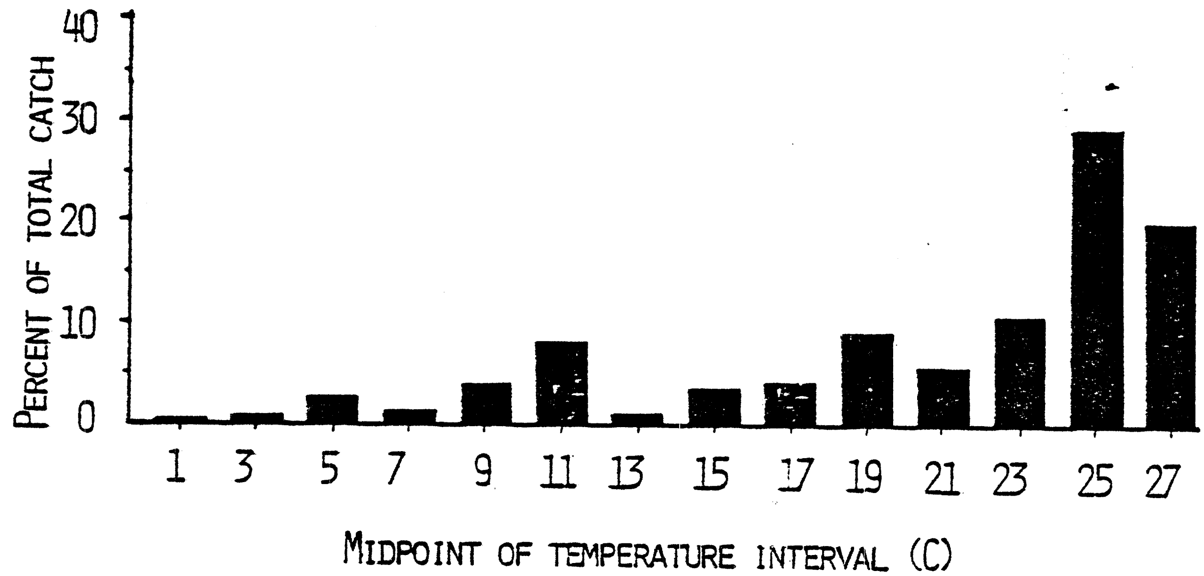


Fig. B38. Percentage of the combined total standard series catch of spottail shiners for 1973 and 1974 collected from different temperatures at Cook Plant study areas, southeastern Lake Michigan.

fish. Temperature catch data for yellow perch, alewives, johnny darters and white suckers also showed smaller fish were more often caught in warmer water than large fish. McCauley and Read (1973) through laboratory experiments indicated that temperatures selected by juvenile yellow perch were usually higher than those selected by adults. Evidently some fish species select different temperatures depending on age-size of individuals.

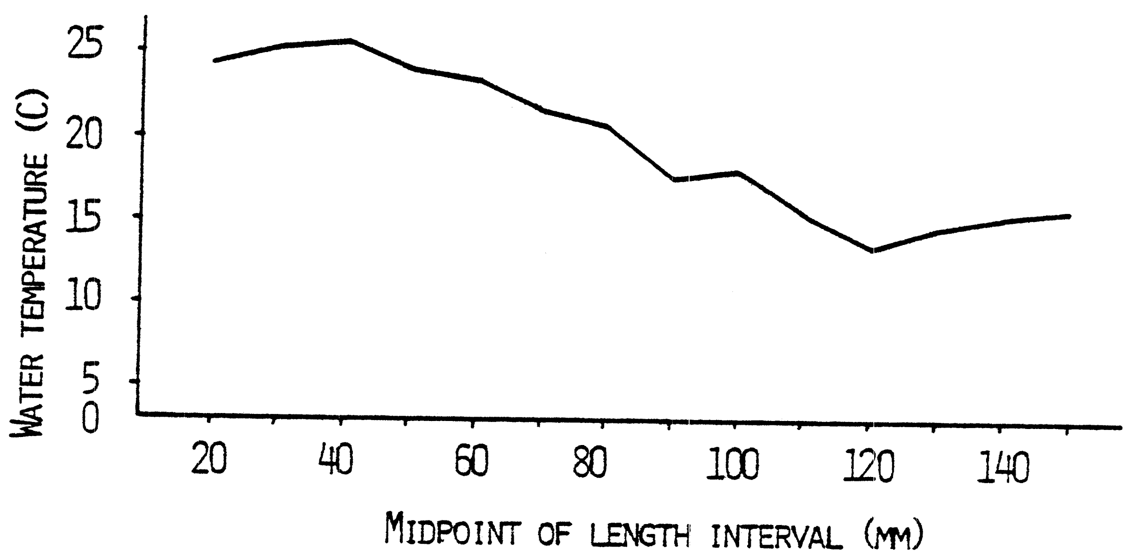


Fig. B39. Mean temperature at which different sizes of spottail shiners were captured during 1973 and 1974 in standard series nets at Cook Plant study areas, southeastern Lake Michigan.

While age plays a role in temperature preferences, season also appears to be very important. Reutter and Herdendorf (1974) through laboratory experiments on Lake Erie fish found thermal preferenda to vary with season, indicating the importance of past thermal history and anticipatory thermoregulation. They found winter-caught adult spottail shiners preferred a temperature of 10.2 C and spring-caught adults preferred a temperature of 14.3 C. Adults in our area were most often caught between 13-16 C. While our data are from all seasons, most adult spottails were caught in spring and early summer and data are most reflective of these seasons. Our data are also not strictly thermal preference, but are prejudiced by other behavioral functions such as spawning and habitat preference.

Other considerations -- In 1973, we postulated that spottail shiners were reaching large sizes because of a lack of predation by piscivorous fish. Data from 1974 led to the same conclusion. Preliminary data on stomach analyses revealed that only 4% of the piscivorous fish caught in the study area were eating spottails (Table B27). Most piscivores were eating alewives (see Table B21); some smelt and sculpins were also consumed. Apparently the large numbers of alewives and their pelagic nature make them a preferred food item of piscivores. Brazo (1973) found that although spottail shiners were present in large numbers during summer in the inshore region of central Lake Michigan, yellow perch did not feed upon them. Wells and House (1974) also have indicated that spottails were not an important forage fish in Lake Michigan.

Table B27. Numbers of examined piscivorous fish, caught during 1973 and 1974 at Cook Plant study areas of southeastern Lake Michigan, which had spottail shiners in their stomachs.

Species	Number of fish examined with food in the stomach	Number of fish examined eating spottail shiners
Yellow perch	124	9
Northern pike	42	6
Burbot	13	2
Lake trout	104	2
Brown trout	65	1
Coho salmon	86	1
Rainbow trout	23	0
Chinook salmon	11	0
Smelt	17	0
Totals	485	21

Preliminary data on feeding by spottail shiners revealed several differences in feeding habits by year, season, time of day and sex (Table B28). Most feeding occurred in fall, with spring and then summer ranking next in importance. Peak feeding in the fall was probably related to post-spawning behavior and availability of food. In general, higher percentages of fish with food in their stomachs occurred in spring 1974 than in spring 1973. Exact causes for this variation are unknown, but fewer stomachs were examined in spring 1973 (115) than in 1974 (560). For males low percentages of stomachs that contained food in fall 1974 may also be related to low numbers examined--28 in 1974, 63 in 1973.

Table B28. Percentages of spottail shiners examined with food in the stomach. Fish were collected during 1973-1974 in standard series nets at Cook Plant study areas, southeastern Lake Michigan.

		Spring (Mar Apr May)	Summer (Jun Jul Aug)	Fall (Sep Oct Nov)
			1973	
Day	Female	47	95	96
	Male	30	44	60
	Immature	5	58	71
Night	Female	12	47	70
	Male	14	65	60
	Immature	70	94	93
			1974	
Day	Female	82	79	98
	Male	62	64	27
	Immature	53	46	45
Night	Female	45	36	57
	Male	60	58	15
	Immature	84	83	94

	1973		1974	
	Day	Night	Day	Night
Female	93	49	87	44
Male	46	58	58	56
Immature	56	93	48	86

While males showed small differences in day-night feeding, females were definitely feeding more during the day (Table B28). In contrast to mature individuals, immature fish were feeding more at night. These feeding differences suggest that there were different behavior patterns depending on size and sex of fish which may be consequently affecting distributions. Due to time restraints, spatial and temporal distribution data could not be examined by sex, but the above data review indicated that this should be considered in future analyses.

In 1973, examinations of spottails revealed a diseased condition on some fish (Jude et al. 1975, p. 105), again in 1974, several fish were found with the same disease. We reported 50-100 diseased fish in 1973, but more detailed data analysis revealed only 20 fish; in 1974, 22 fish were found. The low incidences may reflect inexperience with fish diseases by some of our workers and not actual infection rates. Samples of these fish were examined by Dr. F. P. Meyer of the U.S. Fish and Wildlife Service, Fish Control Laboratory, LaCrosse, Wisconsin. He reported *Thelohanellus notatus* forms (Myxosporidea) as the causative agent, producing large cysts in the lateral musculature. The disease is transferred from fish to fish by ingestion of spores released from ruptured cysts. Following ingestion, the sporoblasts leave the spore, enter the body proper and migrate to the target tissue forming a new cyst. A second myxosporidian, *Myxosoma grandis*, was also abundant in the liver and viscera. This species has been reported from spottails before, and has a life cycle similar to *T. notatus*, with spore release occurring through the gut wall or upon death and decomposition (Hoffman 1970). Meyer felt neither parasite was a primary factor in the health of spottail shiners, but acted as a debilitating force which may render the host susceptible to other diseases and stresses. Further, he concluded that abundance of *Myxosoma grandis* suggests that the population of spottail shiners must be very high or extremely localized. This conclusion closely agreed with our 1973 findings, that locally, spottail shiners were reaching a population peak.

The parasitized fish collected in 1974 were predominantly caught in June (12 fish). Two were caught in May, five in July and two in August. Both sexes were parasitized--ten females, eight males, and four undetermined because of poor condition. Average size of males was 95 mm (range 85-105) and for females 103 mm (range 85-122). Fifteen infected fish were seined, five trawled, one gillnetted and one impinged. Most infected fish being caught in summer and in the beach zone was another indication that the parasite is being spread by crowded conditions. Spottails were most abundant in the beach zone during summer. Catches of infected fish were higher at Cook (18) than at Warren Dunes (4). Some of this difference was a result of increased fishing effort and greater abundance of spottails at Cook.

Rainbow Smelt --

The rainbow smelt is an anadromous species that was introduced into Lake Michigan about 1922 (MacCallum and Regier 1970). Smelt reside primarily in cool offshore waters. Adult smelt enter nearshore waters

during the spring for spawning when they are taken with dip nets by sport fishermen. They are also taken by sport fishermen in the winter by angling through the ice in Newfoundland, Quebec and parts of the Maritime Provinces (Scott and Crossman 1973). Smelt are harvested commercially in the Great Lakes with otter trawls (Scott and Crossman 1973).

Smelt are preyed upon by a variety of creatures--lake trout, landlocked salmon, brook trout, burbot, walleye, perch, gulls, crows and their own species (Scott and Crossman 1973). While smelt are likely important in the diet of Lake Michigan lake trout, we have found that alewife are by far the most important forage fish for larger salmonids, at least in the inshore zone.

Statistical analysis --

Trawls -- Results of analysis of variance (ANOVA) (Table B29) for 1973-1974 showed significant ($P \leq .01$) main effects due to YEAR, MONTH, AREA and DEPTH. TIME, which was a significant main effect in 1973, was not significant in the 1973-1974 ANOVA. Significance between years appeared in the YEAR x MONTH (YxM) and YEAR x TIME (YxT) interactions (Fig. B40). The YxM interaction was due to differences in four particular months: April, June, August and September. Differences in smelt catch between April 1973 and April 1974 were attributed to a larger population of smelt in the Cook Plant area during April 1973 (1358 trawled) than in April 1974 (308 trawled). Differences between years for June, August and September were due to yearling smelt moving inshore along with upwelling waters during sampling in these months in 1973.

The YxT interaction showed a decrease in the total smelt catch for 1974 (5125 fish) compared to 1973 (13,474 fish). There was also a change from larger day catches in 1973 to somewhat larger night catches in 1974.

Depth distributions of yearling and YOY smelt, the only age-classes susceptible to trawling because of their size and distribution, were readily apparent from DEPTH x TIME (DxT) and MONTH x DEPTH (MxD) interactions (Fig. B40). Smelt were consistently more abundant at the 9-m than 6-m stations. Vertical migration of smelt off the bottom at night, hypothesized for YOY by Jude et al. (1975) and reported for adults by Ferguson (1965), was generally supported by the DxT interaction. This interaction showed night catches to be generally smaller than day catches; an expected pattern for a bottom fishing gear and nocturnally pelagic species.

The MxD and MONTH x TIME (MxT) interactions (Fig. B41) showed smelt numbers to peak twice a year, in early spring and late summer. The early spring peak was the result of yearling smelt moving inshore as the water warmed. The late summer peak was composed of YOY which were not large enough to be retained by the trawl until August.

Table B29. Summary of analysis of variance for smelt caught in trawls at Cook Plant study areas from April through October 1973 and 1974.

Source of variation	df	Adjusted mean square[1]	F-statistic
YEAR	1	14.65975	142.07**
MONTH	6	5.21473	50.54**
AREA	1	.74044	7.18*
DEPTH	1	12.51766	121.31**
TIME of day	1	.00513	.05
YxM	6	1.73627	16.83**
YxA	1	.04110	.40
MxA	6	1.17951	11.43**
YxD	1	.01919	.19
MxD	6	.64041	6.21**
AxD	1	.38825	3.76
YxT	1	3.06975	29.75**
MxT	6	.59754	5.79**
AxT	1	.03187	.31
DxT	1	.94703	9.18*
YxMxA	6	.31222	3.03*
YxMxD	6	1.79791	17.43**
YxAxD	1	.76605	7.43*
MxAxD	6	.49679	4.81**
YxMxT	6	2.46758	23.91**
YxAxT	1	.39180	3.80
MxAxT	6	.20350	1.97
YxDxT	1	.18895	1.83
MxDxT	6	.16686	1.62
AxDxT	1	.07581	.73
YxMxAxD	6	.38832	3.76*
YxMxAxT	6	.41633	4.03*
YxMxDxT	6	.46045	4.46**
YxAxDxT	1	.01057	.10
MxAxDxT	6	.27678	2.68
YxMxAxDxT	6	.27139	2.63
Within cell error	110[2]	.10318	

** Significant ($P < .001$).

* Significant ($P < .01$).

1 Mean squares were multiplied by harmonic cell size/maximum cell size ($n_h/N = .9825$) to correct for 2 missing observations where the cell mean was substituted.

2 Two degrees of freedom were subtracted to correct for 2 missing observations where the cell mean was substituted.

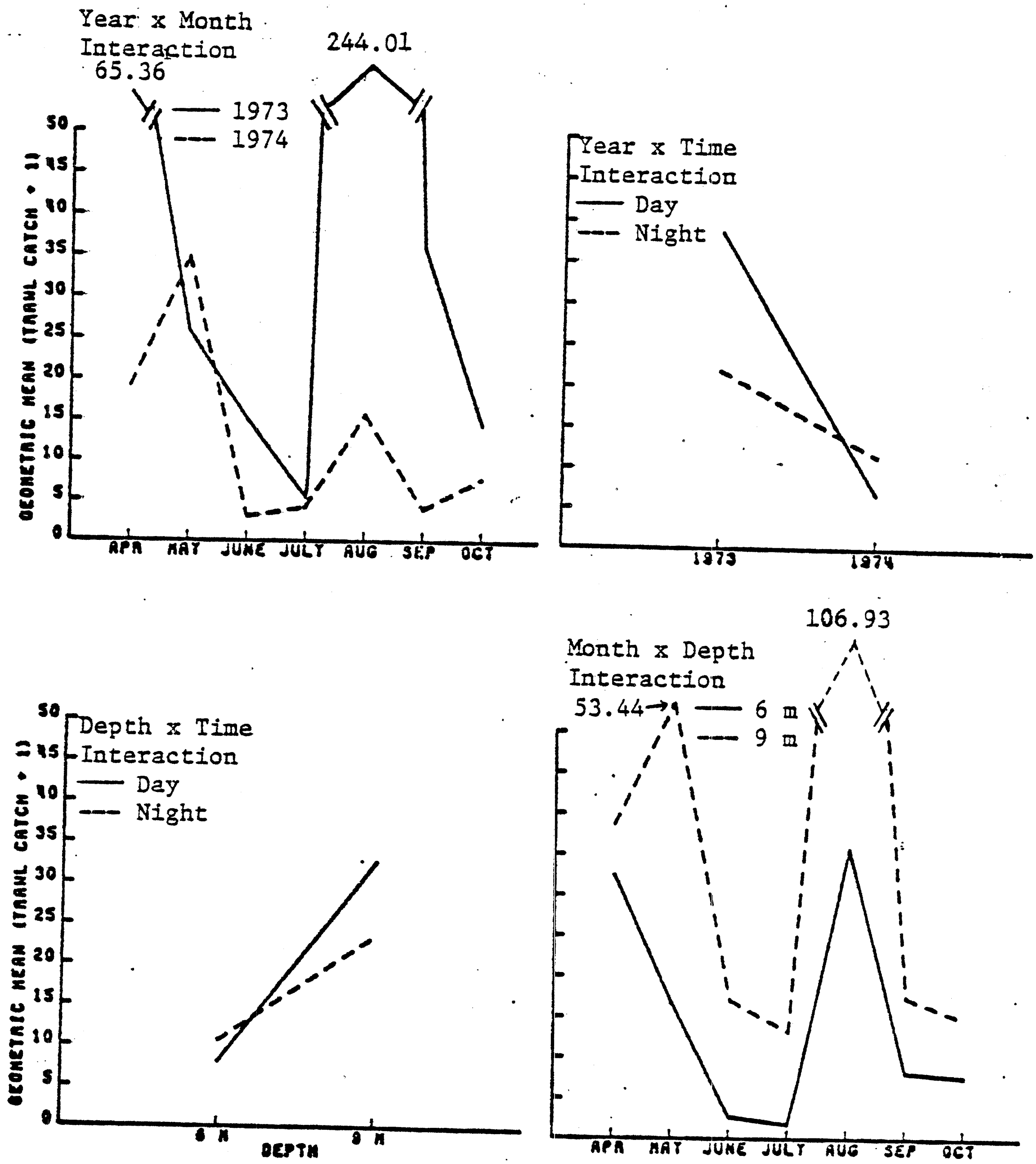


Fig. B40. Geometric mean number of rainbow smelt caught in duplicate standard series trawls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

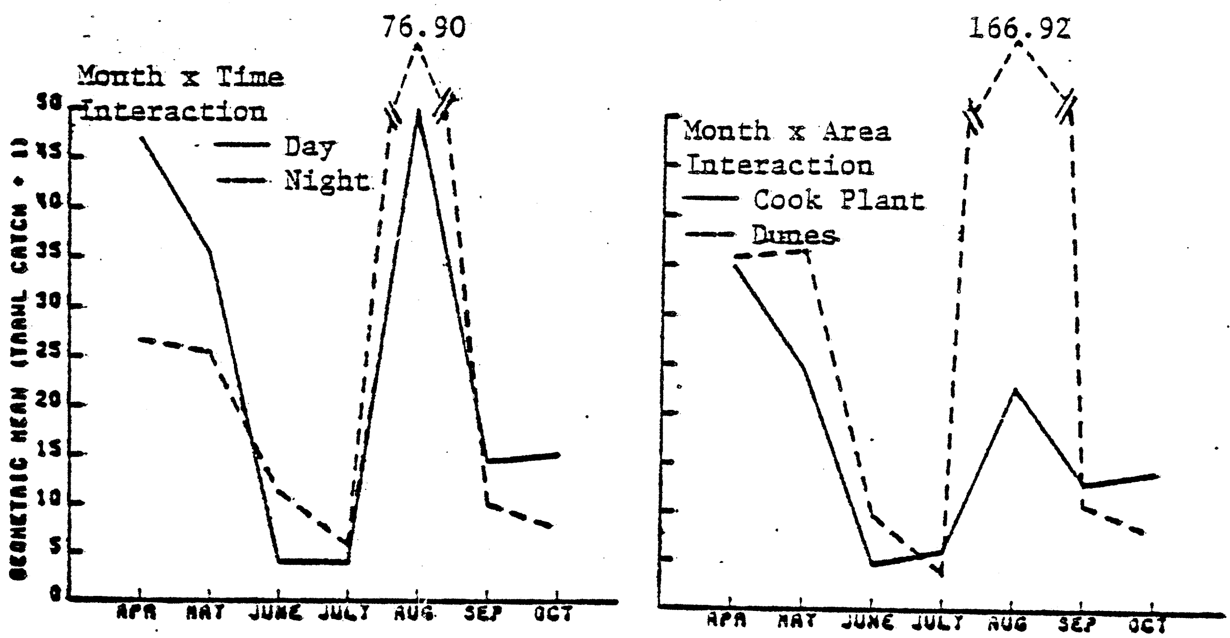


Fig. B41. Geometric mean number of rainbow smelt caught in duplicate standard series trawls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

The MONTH x AREA (MxA) interaction (Fig. B41) showed YOY and yearling smelt to be somewhat more abundant at Warren Dunes stations than at Cook Plant stations. The pronounced difference between Warren Dunes and Cook during August was due to an upwelling during sampling which primarily affected Warren Dunes.

All observed interactions can be traced to three causative factors: seasonal movements of different smelt age-classes through the sampling areas, yearly fluctuations in population density and upwellings during some sampling periods. No determinations from third- or fourth-order interactions were made owing to their complex nature; second-order interactions were most useful for examining the biology of smelt.

Gill nets — Nonparametric statistics were used for gill net catches in 1973 and 1974 because the assumptions of normality necessary for parametric statistics could not be met. Statistical analyses of 1973 and 1974 smelt catches were done using the Median (Sign) and Wilcoxon tests (Table B30). Results of the Median test found only one significant cell (P=.0312), i.e. the 1974 Cook Plant 9-m station had a larger catch than the 6-m station during the day. The Wilcoxon test also found this cell significant (P=.025).

The Wilcoxon test also detected a significant difference (P=.01) between catches at the 9-m stations at Warren Dunes and Cook at night during 1973. Larger catches at Warren Dunes during August and September, the result of upwellings during sampling, were responsible for the interaction.

Table B30. Results of Wilcoxon and Median (Sign) tests of paired comparisons of standard series gill net catches of rainbow smelt in Cook Plant study areas, southeastern Lake Michigan during 1973 and 1974. Factors were Year, Area, Depth and Time with comparisons in the table given in the same order. Tests were conducted at $\alpha = .10$. NS = Nonsignificant; NT = No test, insufficient non-zero differences.

TEST	TEST RESULTS							
YEAR	Cook Plant				Warren Dunes			
	6M		9M		6M		9M	
	day	night	day	night	day	night	day	night
Wilcoxon	NT	NS	NS	NS	NS	NS	NS	NS
Median	NT	NS	NS	NS	NS	NS	NS	NS
AREA	1973				1974			
	6M		9M		6M		9M	
	day	night	day	night	day	night	day	night
Wilcoxon	NS	NS	NS	Dunes>Cook	NT	NS	NS	NS
Median	NS	NS	NS	NS	NT	NS	NS	NS
DEPTH	1973				1974			
	Cook Plant		Warren Dunes		Cook Plant		Warren Dunes	
	day	night	day	night	day	night	day	night
Wilcoxon	NT	NS	NS	NS	9M>6M	NT	NT	NS
Median	NS	NS	NS	NS	9M>6M	NT	NT	NS
TIME	1973				1974			
	Cook Plant		Warren Dunes		Cook Plant		Warren Dunes	
	6M	9M	6M	9M	6M	9M	6M	9M
Wilcoxon	NS	NS	NS	NS	NS	NS	NT	NS
Median	NS	NS	NS	NS	NS	NS	NT	NS

Nonparametric statistics did not fit our smelt data well because smelt taken in gill nets are a transient population. Smelt entered the sampling areas in spring for spawning, then departed to deeper waters. Catches of adults during summer months were associated only with upwellings, which resulted in sporadic occurrences of adults throughout the year with many zero catches.

Seines -- Parametric statistical tests were not performed on seine data because assumptions of the tests were not met by transformed data. Nonparametric tests were also not used because of very low catches during most months. The only months when appreciable numbers of smelt were seined were April and May. These smelt concentrations were the result of spawning activities.

Seasonal distribution by age-size class --

Adults -- Due to our limited sampling regime (no regular sampling beyond the 9-m contour) and infrequent winter sampling, little can be directly said about winter distribution of smelt. MacCallum and Regier (1970) reported adult smelt to be dispersed in the central basin of Lake Erie from mid-March to early April and in general utilized depths greater than 18 m. Galligan (1962) reported winter catches of smelt (age-class not stated) from depths of 6-46 m in Cayuga Lake, with the majority of fish taken at about 14 m. In Lake Erie, Ferguson (1965) reported the winter distribution of smelt as widespread and states that they were taken in extremely shallow water by anglers fishing through the ice.

Our limited winter gillnetting data indicated that smelt in southeastern Lake Michigan also overwinter in deep water (21-m depth and greater). Day sets in 1974 at 6 and 9 m off Cook were devoid of smelt and sets off Cook at 21 m caught only one smelt during the day and two at night. Therefore, it is felt that smelt overwinter at depths greater than 21 m in the Cook Plant vicinity. This depth range is in line with the 13-64-m range reported by Wells (1968) for the distribution of smelt in February in southeastern Lake Michigan.

March was the first month in 1973 (Fig. B24 Jude et al. 1975) and 1974 (Fig. B42) when significant numbers of smelt appeared in the Cook Plant vicinity. Gillnetting in March 1973 collected smelt at all 6- and 9-m stations; whereas, in 1974 (Fig. B43), they were only taken off Cook. Adult smelt were not taken in seines during March of either year, but smelt apparently were moving inshore in preparation for spawning.

Gill net and seine data for April 1973 and 1974 (the only month in which adults were taken in seines) showed a general pattern of diel migration from 6-m and 9-m stations to beach stations for spawning during the night. This was evidenced by gill net catches of smelt being confined primarily to day sets while high seine catches were confined primarily to night fishing. Exceptions to this pattern occurred at stations B (beach zone south of Cook) and G (6-m Warren Dunes) during April 1973, and station C (6-m Cook) during April 1974. Reasons for these variations are not clear;

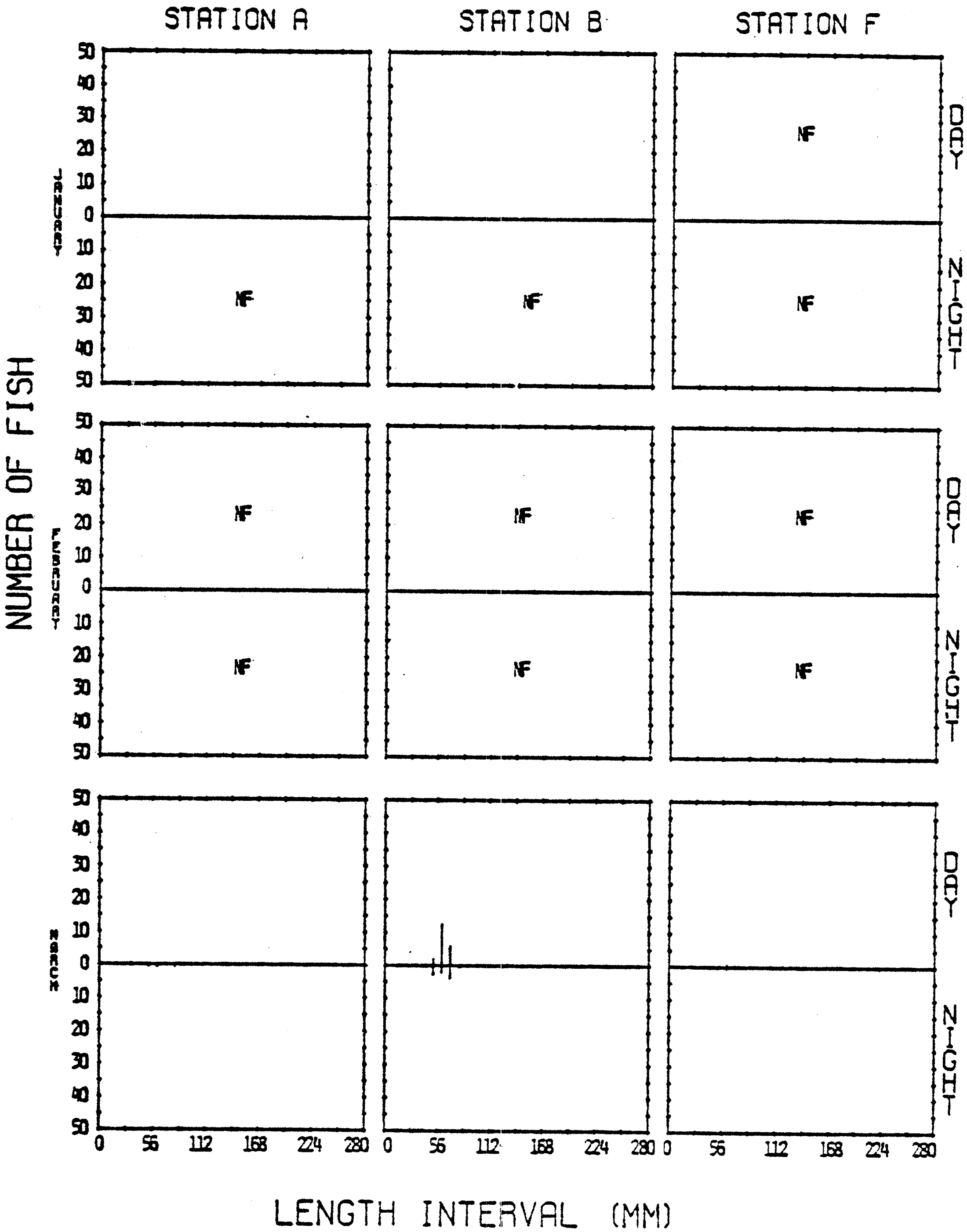
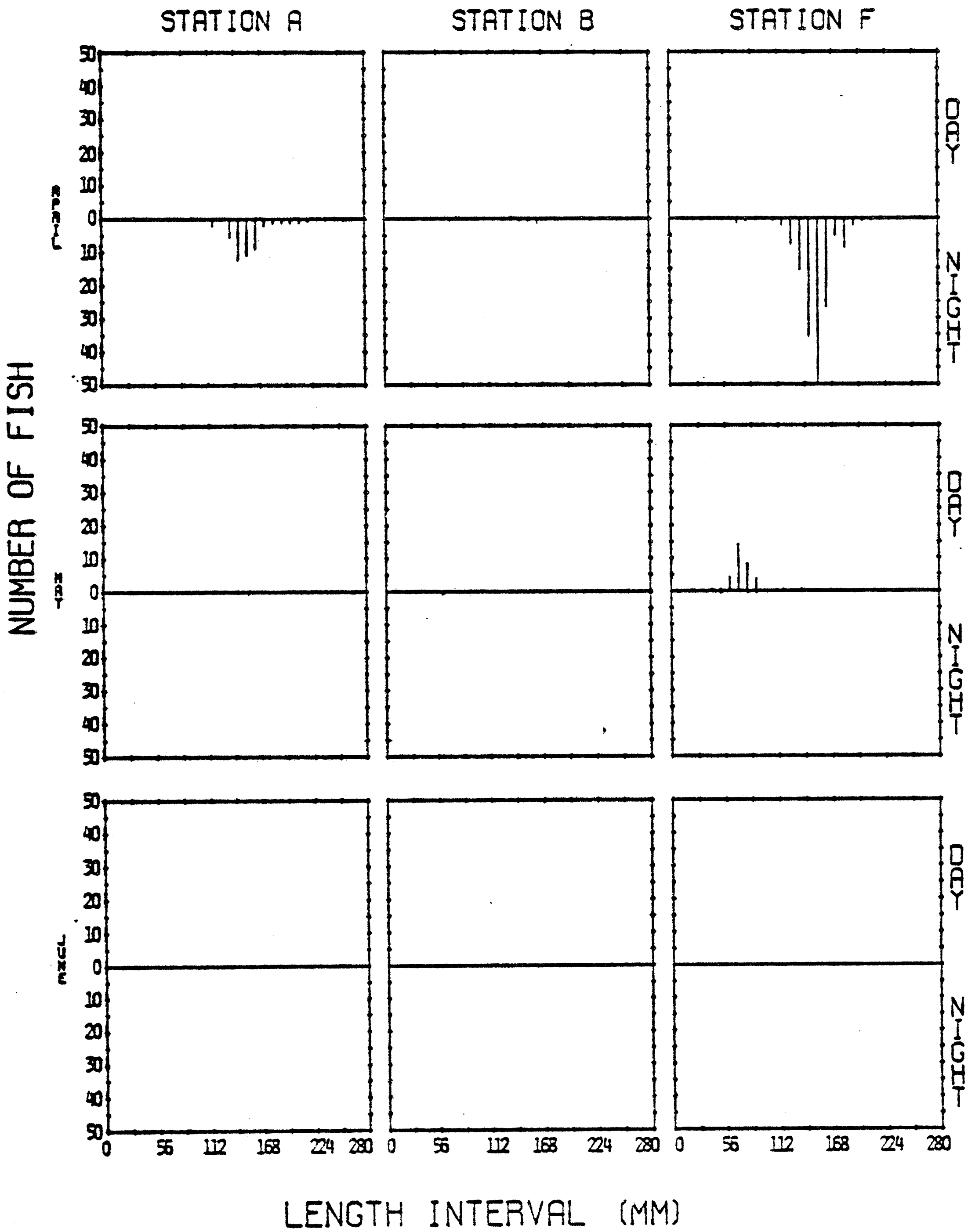


Fig. B42. Length-frequency histograms for rainbow smelt caught by standard series seining during 1974 at Cook Plant study areas, southeastern Lake Michigan. NF = not fished.



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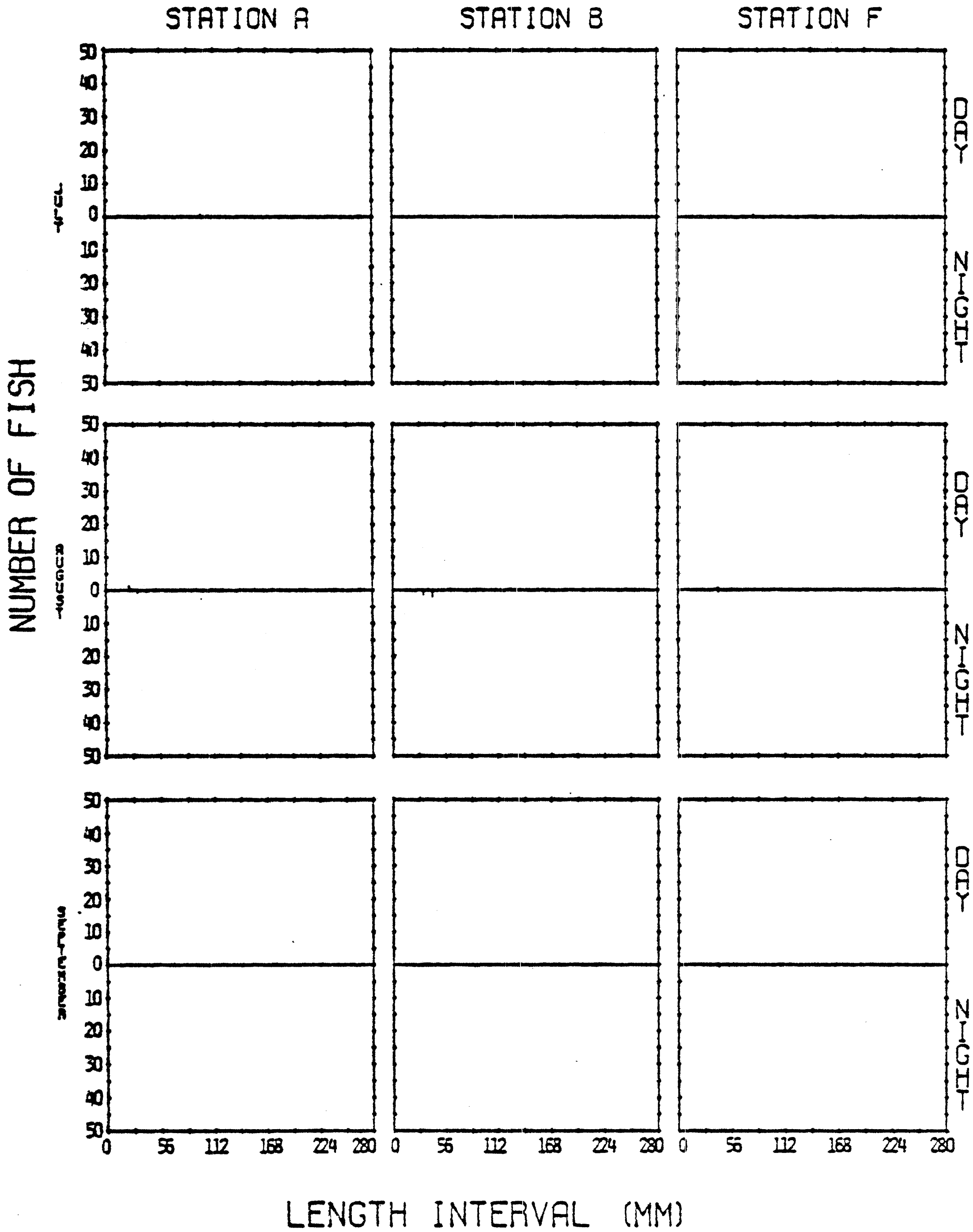

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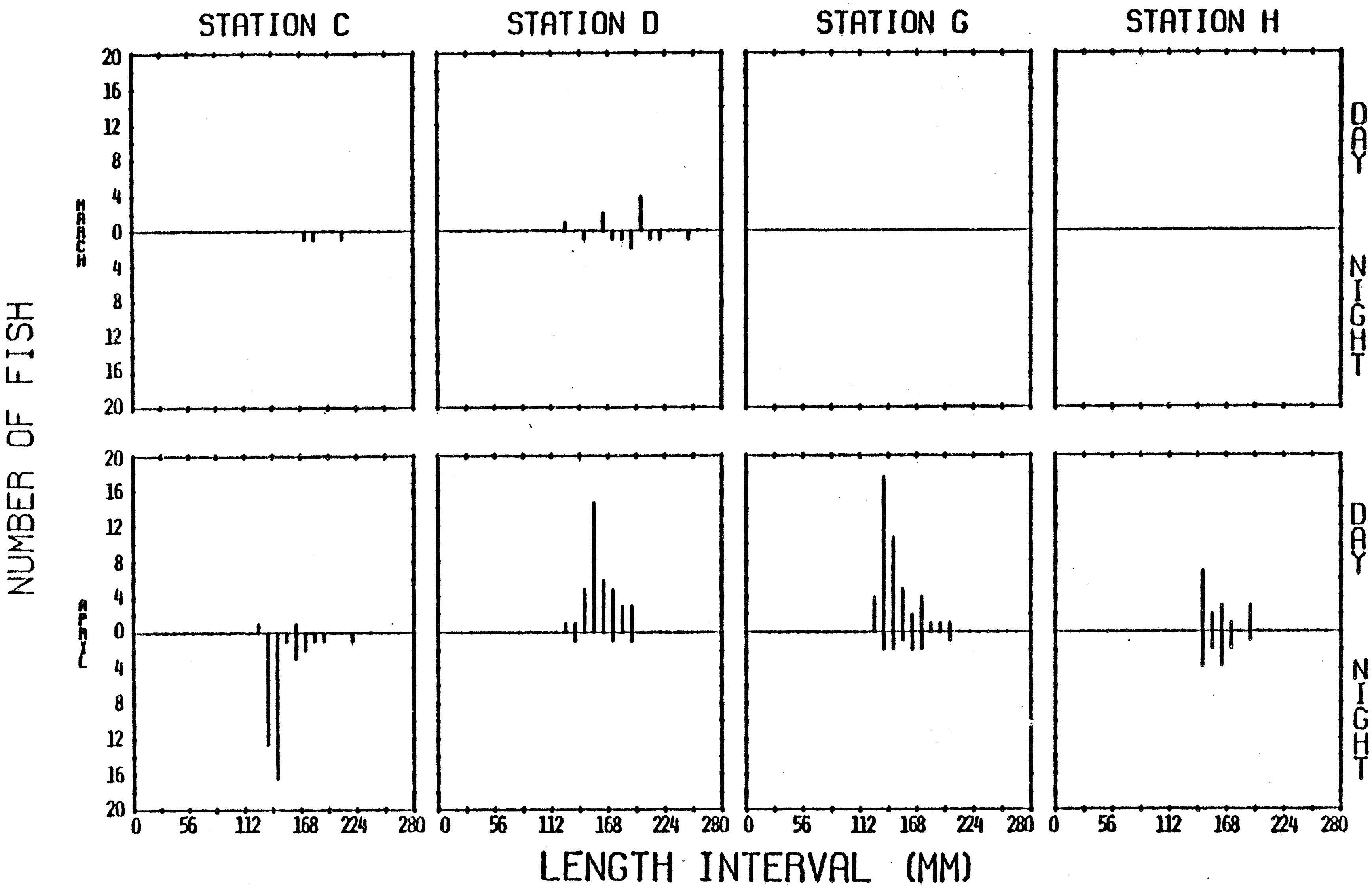
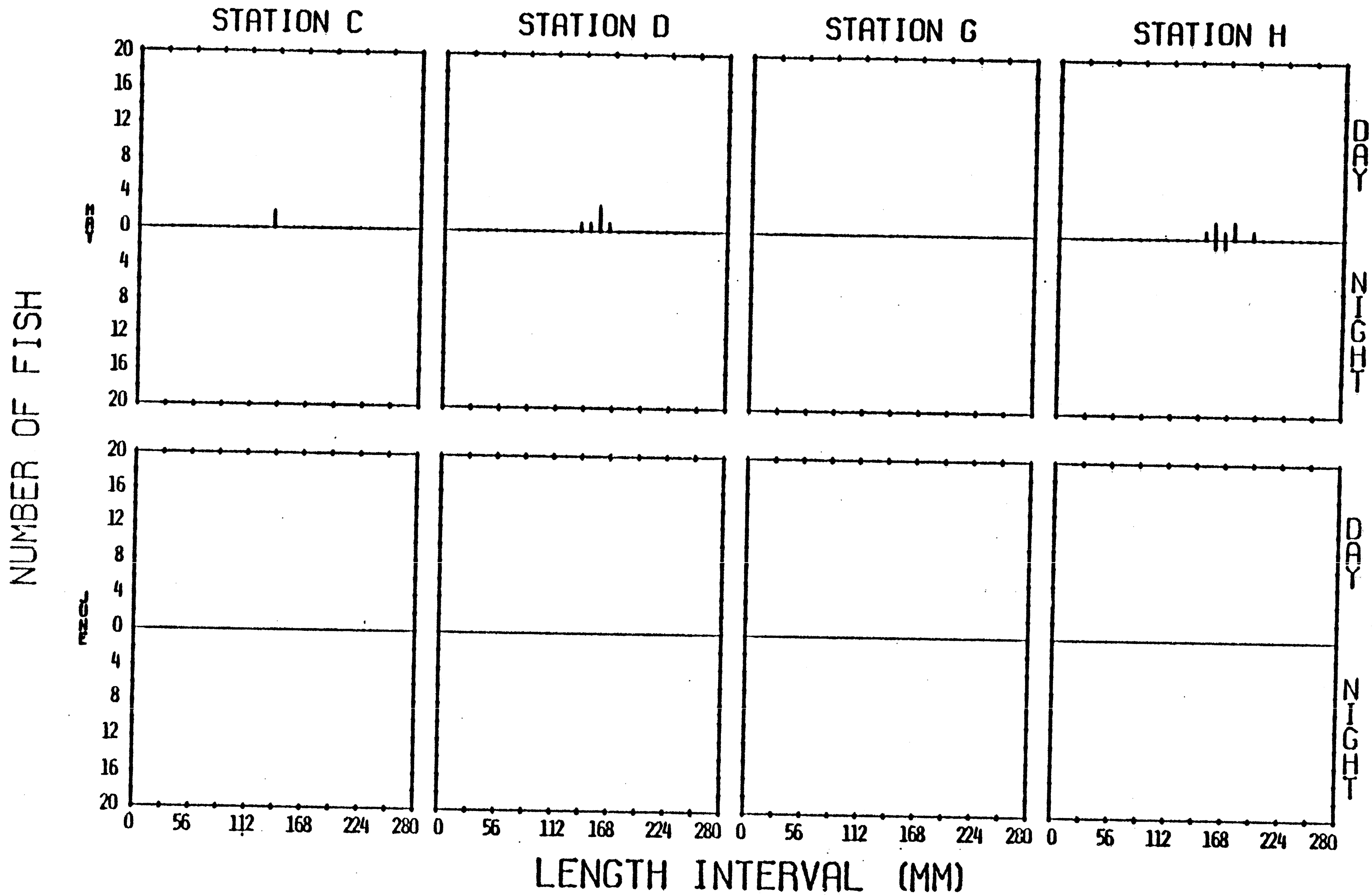


Fig. B43. Length-frequency histograms for rainbow smelt caught by standard series gillnetting during 1974 at Cook Plant study areas, southeastern Lake Michigan.



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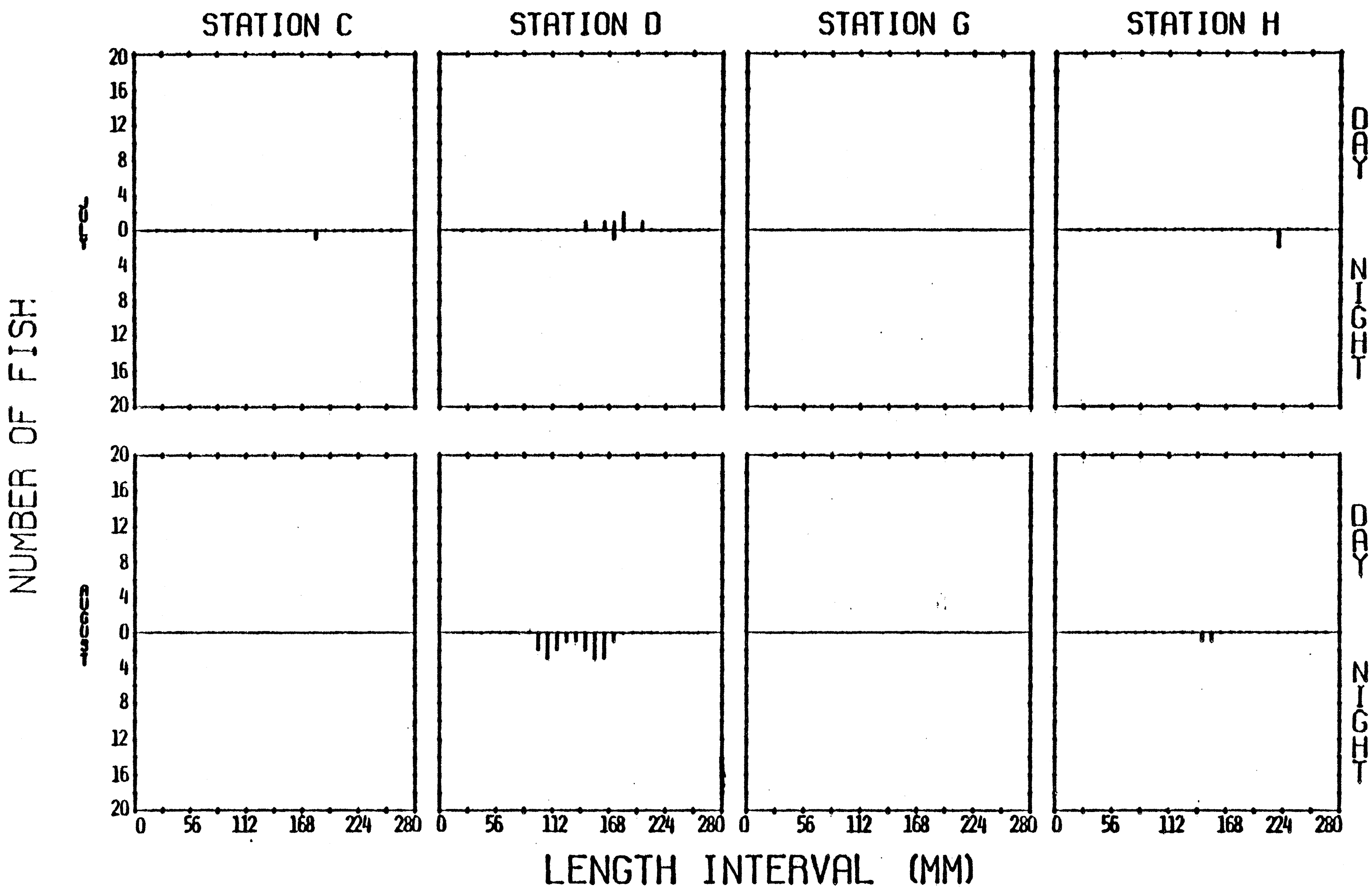

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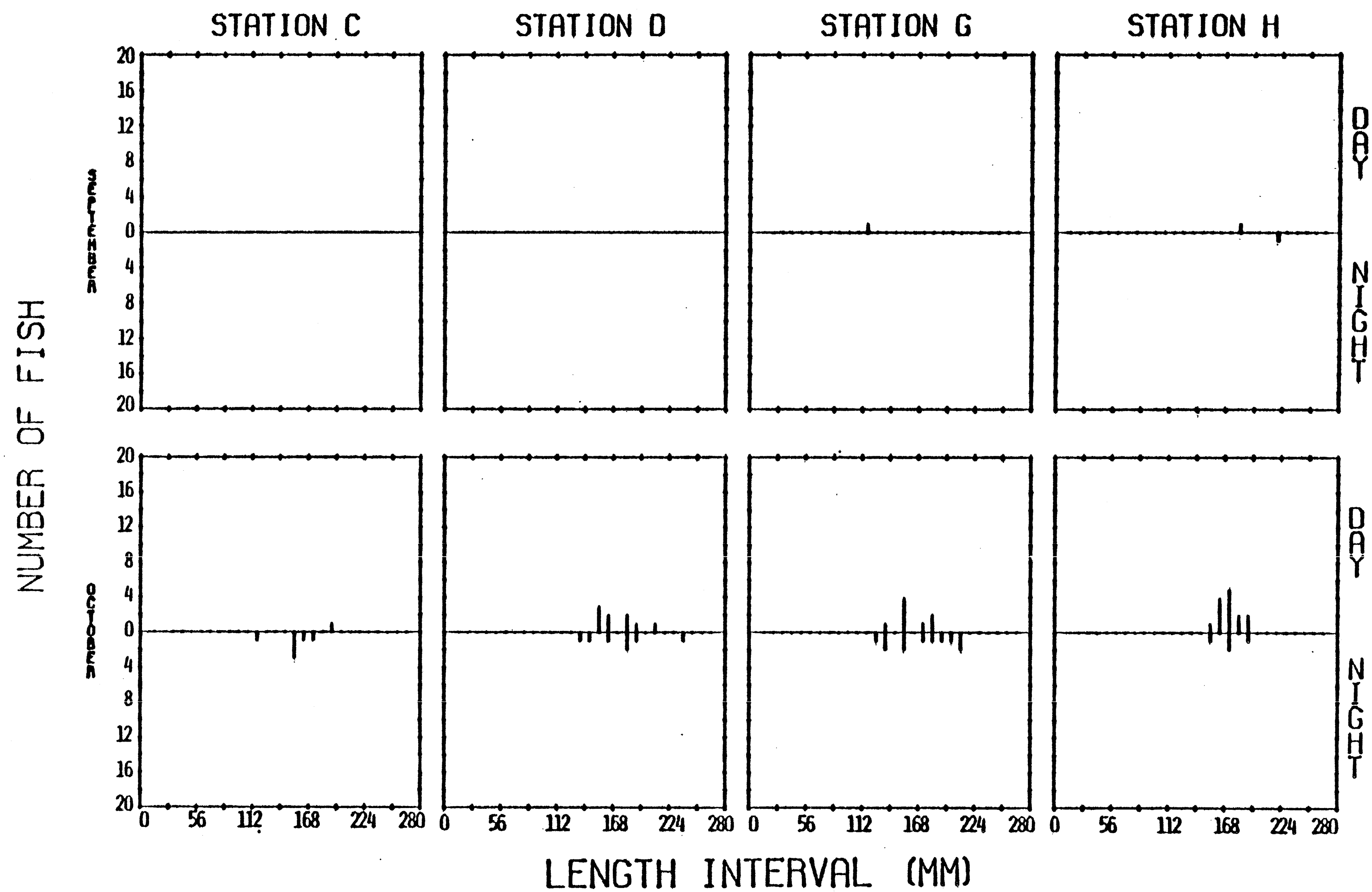

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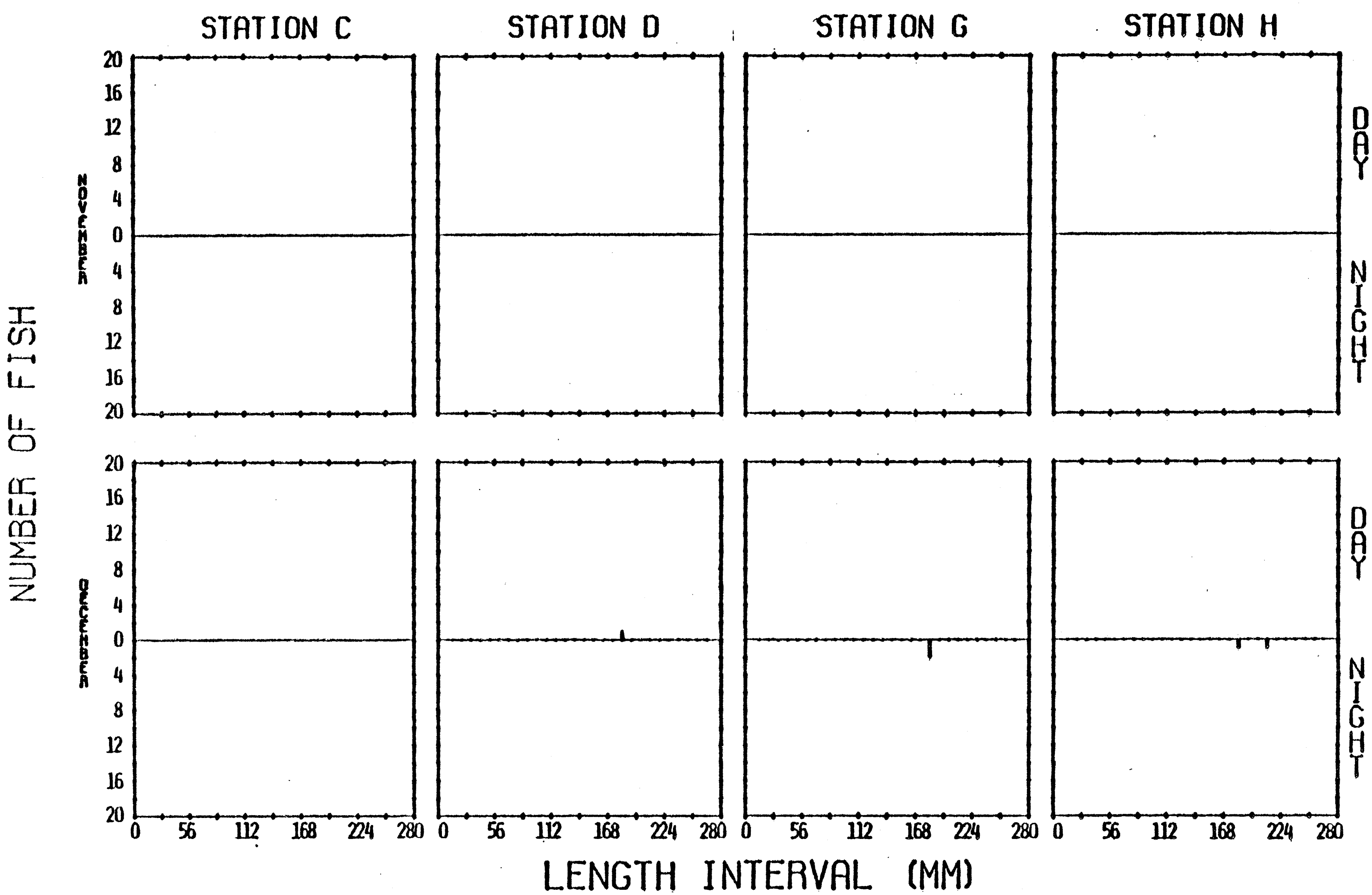


Fig. B43. Continued.

however, the proximity of the safe harbor (removed prior to the 1974 field season) to beach station B (S Cook) was thought to have been a factor.

Gonad data for 1973 (Table B22 Jude et al. 1975), and 1974 (Table B31) showed that spawning of smelt began around mid-April and continued to early May. This agreed with Scott and Crossman (1973) who reported spawning to range from March to May, depending on weather and locality.

Smelt spawning in the Cook Plant vicinity probably takes place primarily in the beach zone at night. However two streams, 4- and 8-km south of the Cook Plant at Weco Beach and Warren Dunes respectively, were also thought to be used.

Seining during April 1973 coincided with the spawning peak, judging from the large numbers of spawning smelt seined. Water temperatures at this time indicated an optimum spawning temperature of 8-10 C. Seining in April 1974 was thought to have been completed prior to the spawning peak based on the water temperatures (7.1-7.9 C) and small numbers of spawning fish seined. Therefore, the 7.1-7.9 C water temperature range was felt to reflect the temperatures at the onset of spawning.

Scott and Crossman (1973) reported that for the Great Lakes watershed spawning does not commence until water temperatures reach 8.9 C. This temperature appears to be high since our 1974 data indicate spawning started when water temperature was as low as 7.1 C. The 18.3 C cut-off point for spawning (Scott and Crossman 1973) appears to be quite high. Our data indicate the termination of spawning to occur nearer 10 C. McKenzie (1964) reported early spawners to leave spawning streams in the Miramichi River system, New Brunswick before water temperature reached 10 C and that late spawners left before the temperature reached 15 C. The 10 C upper boundary reported by McKenzie agreed with the observed temperature regime in the Cook Plant vicinity.

After spawning (late April to early May), adult smelt moved offshore to progressively deeper and cooler water as summer approached (Ferguson 1965, MacCallum and Regier 1970, Wells 1968, and Emery 1973). Our gillnetting in May 1974 captured 15 smelt during the day and two at night, which compared to four during the day and three at night for 1973. Subsequent catches of adult smelt throughout summer months corresponded to periods of upwelling.

Young-of-the-year -- Sled tows and mid-water tows conducted from May through July 1974 (see SECTION C) showed the 6-m and especially the 9-m contours to be nursery areas for YOY smelt (<70 mm). It was not until August that YOY smelt became large enough to be retained by our trawl. At this time they were taken at all 6- and 9-m stations (Fig. B44). Young-of-the-year smelt were taken in decreasing numbers at all 6- and 9-m stations from August through October. Young-of-the-year smelt apparently moved futher offshore as they grew larger. This same offshore progression was observed by MacCallum and Regier (1970) in Lake Erie. They reported YOY to have moved to a depth of 15 m by the end of June. Indications that the

Table B31. Monthly gonad conditions of rainbow smelt as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1974 in southeastern Lake Michigan. All fish examined in a month were included except poorly received specimens.

Gonad condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Females												
Poorly dev.					1		6	6	3	4	1	1
Mod. dev.	2		1	5				4	3	29	2	1
Well dev.	1		41	128	3						2	7
Ripe-running				18								
Spent				3	9		5	1	1			
Males												
Poorly dev.	1			4	2		15	22	2	3		1
Mod. dev.	2		8	25	4		9	9	6	32	2	3
Well dev.			12	131	12		1			10	2	4
Ripe-running				1								
Spent				2	28	1	5	12	2			
Unable to Distinguish												
			4	8	39	3	19	12	2	2		
Immature												
	8		65	249	280	56	117	206	87	119	19	

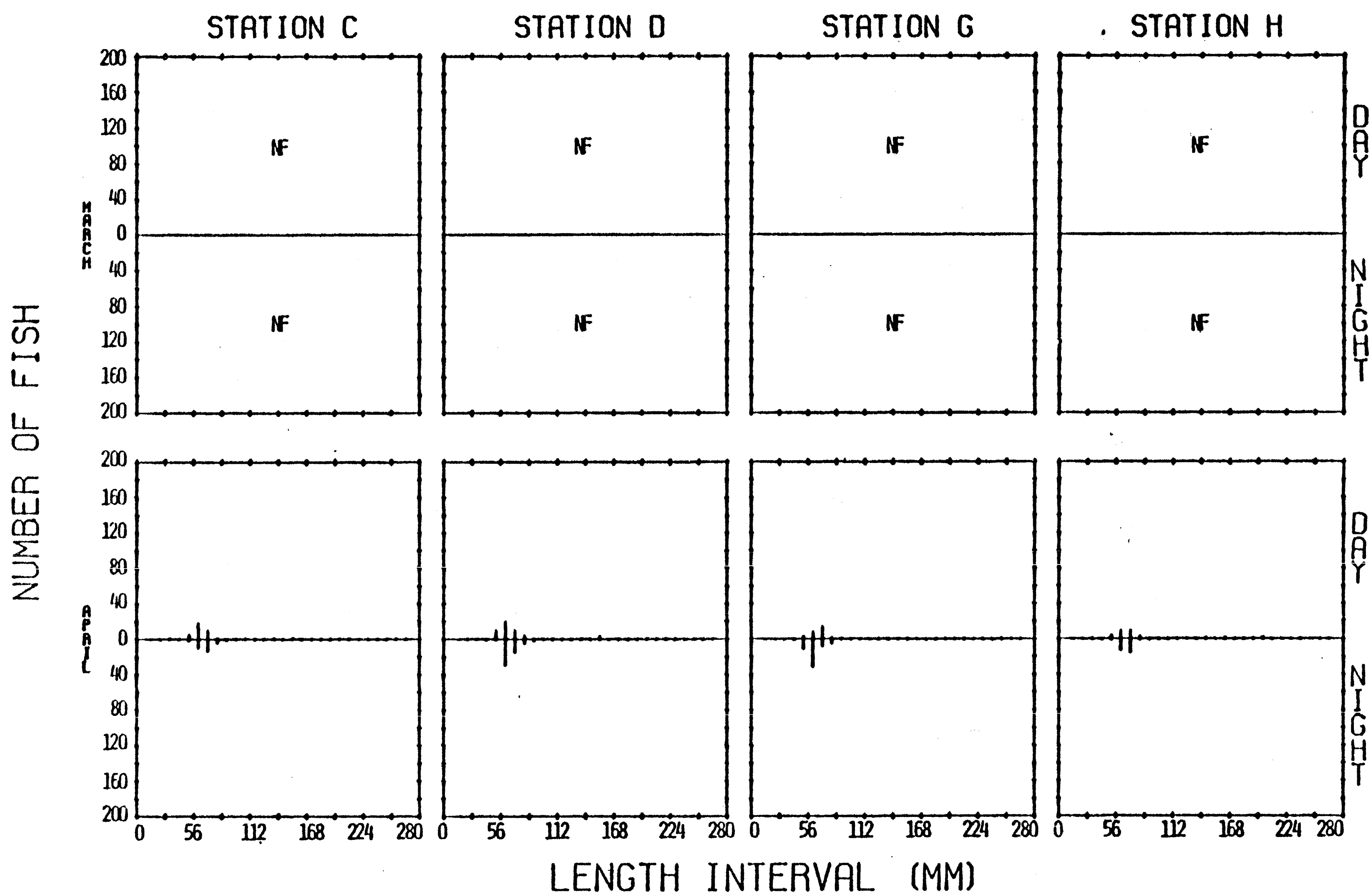
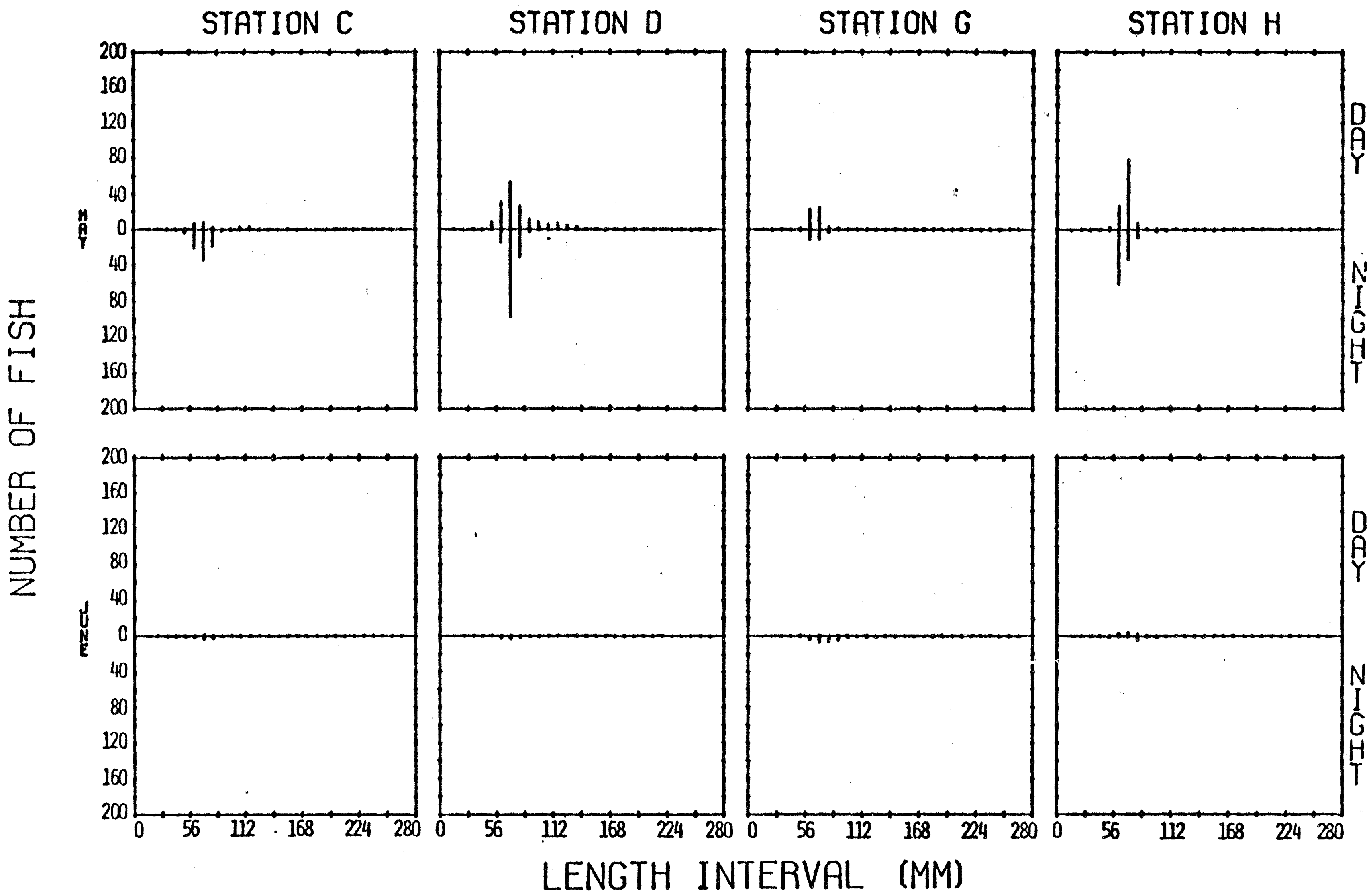


Fig. B44. Length-frequency histograms for rainbow smelt caught by standard series trawling during 1974 at Cook Plant study areas, southeastern Lake Michigan. NF = not fished.



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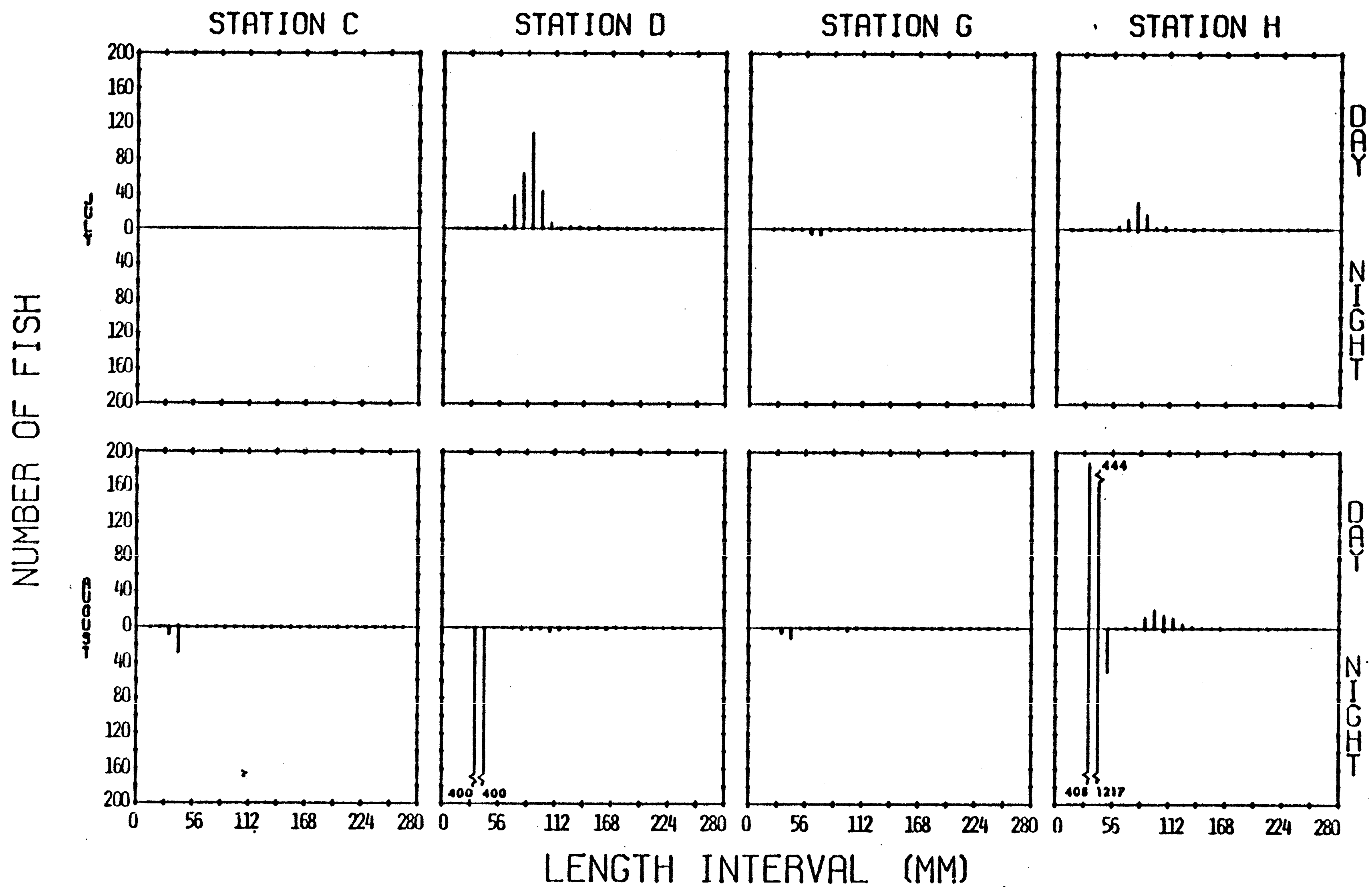

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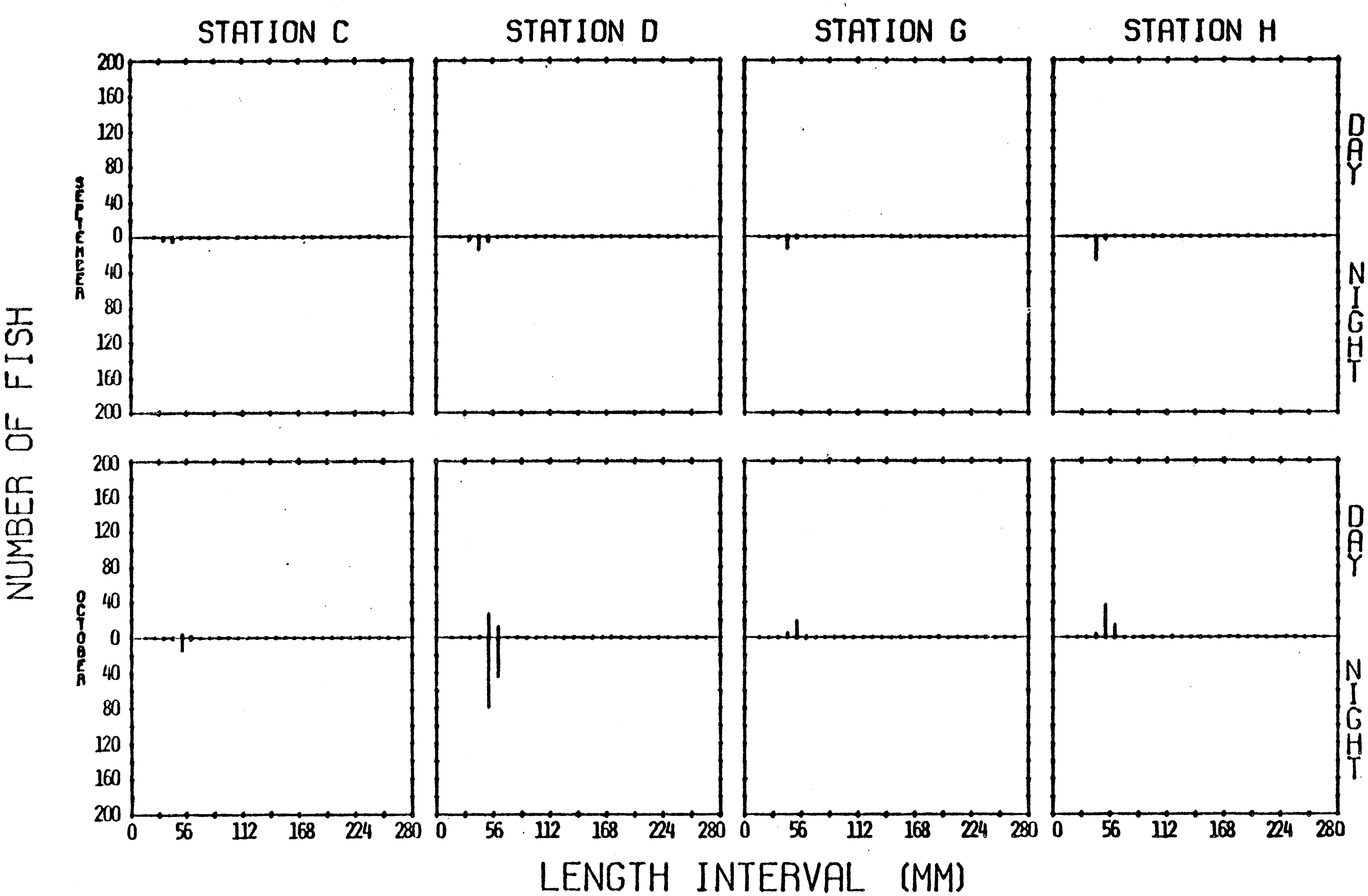

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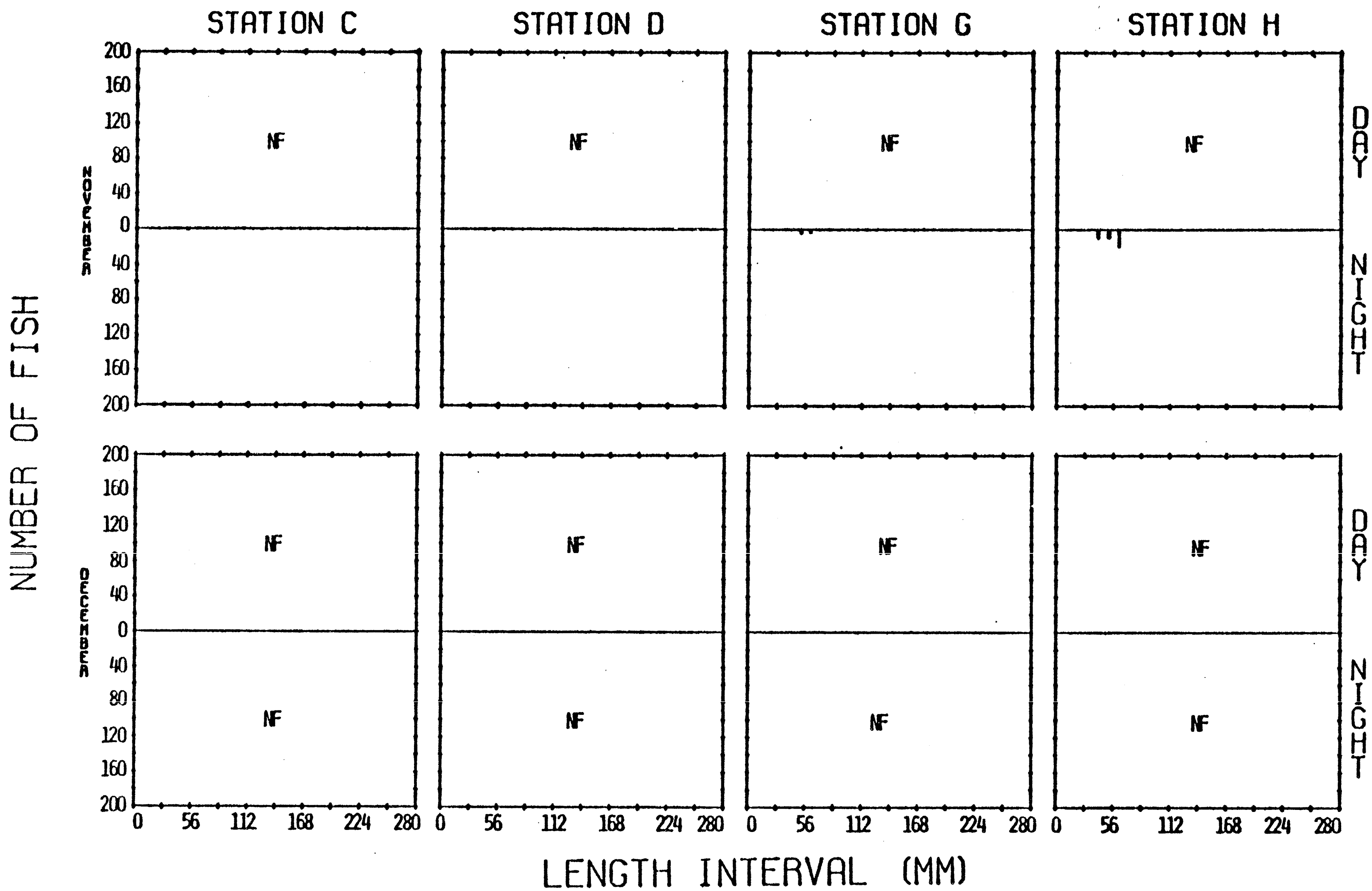


Fig. B44. Continued.

YOY population is indeed further offshore was confirmed by the August 1974 influx of YOY only at stations experiencing upwellings. Stations D and H (9-m Cook and Warren Dunes) were most affected by the August upwelling and correspondingly had largest YOY catches. Absence of YOY from trawls in late fall indicated that they had dispersed into deeper water.

Diel migration of YOY smelt upward at night and downward during the day was observed in our fish larvae tows and by Ferguson (1965). Trawl data for 1973 and 1974 also supported this observation, which is discussed under Statistical analysis -- Trawls.

Yearlings -- Yearling smelt ($\geq$70 mm < 120 mm) due to size and distribution, were taken primarily in trawls and rarely in seines. Seine catches of YOY smelt in 1973 were limited to April and May. April seines captured five yearlings during daylight and 36 at night. May seines captured two yearlings during daylight and 74 at night.

Seining in 1974 captured yearlings in three months: March (23 during the day and 14 at night), April (five at night only) and May (32 during the day and four at night). It is interesting to note the reversal of day-night catch abundance between these months for 1973 and 1974.

Trawling during April and May captured substantial numbers of smelt during 1973-1974 at all stations, day and night. Diurnal catches were generally largest but were not as dominant in 1974 as in 1973. Numbers of yearling smelt taken during June of both years declined at all stations over previous months, with the majority taken at night. In July of both years, yearlings were taken at stations where upwellings occurred. This indicates yearlings had moved further offshore by July into 9-m stations along with cooler upwelling water. MacCallum and Regier (1970) found yearlings in Lake Erie to move offshore beyond 18 m by mid-June. Ferguson (1965) however, in Lake Erie found yearlings abundant at 6 m and 9 m in July and observed the migration to the offshore population to occur in October. After July, we collected yearlings only during upwellings.

Temperature-catch relationships -- Temperature-catch relationships for adult smelt were defined using gill net data. Trawl catches were not used because few adults were taken in trawls. Seine catches were not used because adults taken in seines were spawning and had corresponding alterations in thermal preference. Adult smelt showed a rather narrow temperature preference, 6-8 C, which agreed well with 6.1 C found by Ferguson (1965) and 7.2 C temperature reported by Hart and Ferguson (1966, cited by Scott and Crossman 1973). Wells (1968) reported a temperature range of 6-14 C for smelt. This wide range agrees with our observed over-all range for YOY through adults, but since he did not state the age-classes for which this range applies its usefulness is marginal.

Young-of-the-year and yearling smelt were taken primarily in trawls, therefore, trawl data have been used in determining temperature preferences for these two groups. Preferred temperatures for YOY and yearlings were

reported to range from 12 to 14 C by Jude et al. (1975). Data for 1974 showed a somewhat different regime. YOY smelt were taken in substantial numbers from temperatures ranging from 12 to 18 C, with maximum catches between 13 and 14 C. Yearlings were taken from 6 to 12 C with maximum abundance from 8 to 10 C.

Other considerations -- Growth rates of YOY and yearlings -- Length intervals used in age determinations, and ultimately in growth rate calculations of YOY and smelt, were obtained from length-frequency histograms (Figs. B45 and B46). While this method gave confident results for isolating YOY smelt, there may be some overlap between yearling and age-group 2. However, based upon the expected lengths of smelt at various ages and the configuraton of the histograms, any overlap was felt to be minimal.

Mean length of YOY smelt was 6.0 mm when first collected in April 1973 and May 1974. These smelt were newly hatched, being only a couple days old, based upon the 5.1-mm mean length observed by Jude et al. (1975) for 1-day-old laboratory reared smelt. YOY smelt collected in May 1973 also had a mean length of 6.0 mm. This suggested that no growth took place during the first month of life. More probably, the six larvae collected in May were the result of late spawning activity. Support for this idea was that four of these larvae were collected from the north beach station at Cook and not from the 6-m and 9-m stations. We have found that smelt larvae move from the beach zone to deeper water (6-m and 9-m contours) several days after hatching. Therefore, their presence in the beach zone, along with their length, indicated that they were recently hatched.

No larvae from the April 1973 hatch were observed in May and June 1973 samples. This absence was caused by April larvae being large enough to avoid our plankton nets but too small for our other fishing gear. During the period April 16-July 16, 1973, YOY smelt increased in mean length by 30 mm, for a growth rate of 0.37 mm/day (Table B32). During the following period of July 16-August 22, the growth rate of YOY smelt declined to 0.11 mm/day. The periods of August 22-September 20 and September 20-October 27 showed a steady rise in the growth rate (0.14 mm/day and 0.24 mm/day repectively), but nowhere near the previous rate of 0.37 mm/day. By late October YOY smelt had achieved a mean length of 53 mm and a mean growth rate of 0.26 mm/day for the 184-day period of April 18-October 27, 1973.

YOY smelt collected during 1974 exhibited a similar pattern of growth as found for YOY collected in 1973. There was rapid growth (0.41 mm/day) in in the spring (May 13-June 11) followed by a sharp decline (0.14 mm/day) in early summer (June 11-July 16). Growth (0.41 mm/day) rose sharply in mid-summer (July 16-August 10) and then declined in late summer (August 10-September 10; 0.18 mm/day) and early fall (September 10-October 8; 0.36 mm/day) to rates somewhat ahead of but more in line with those corresponding to this time of year in 1973. By early October 1974 YOY smelt had attained a length of 51 mm and a mean growth rate of 0.30 mm/day for the 148-day period of May 13-October 8, 1974.

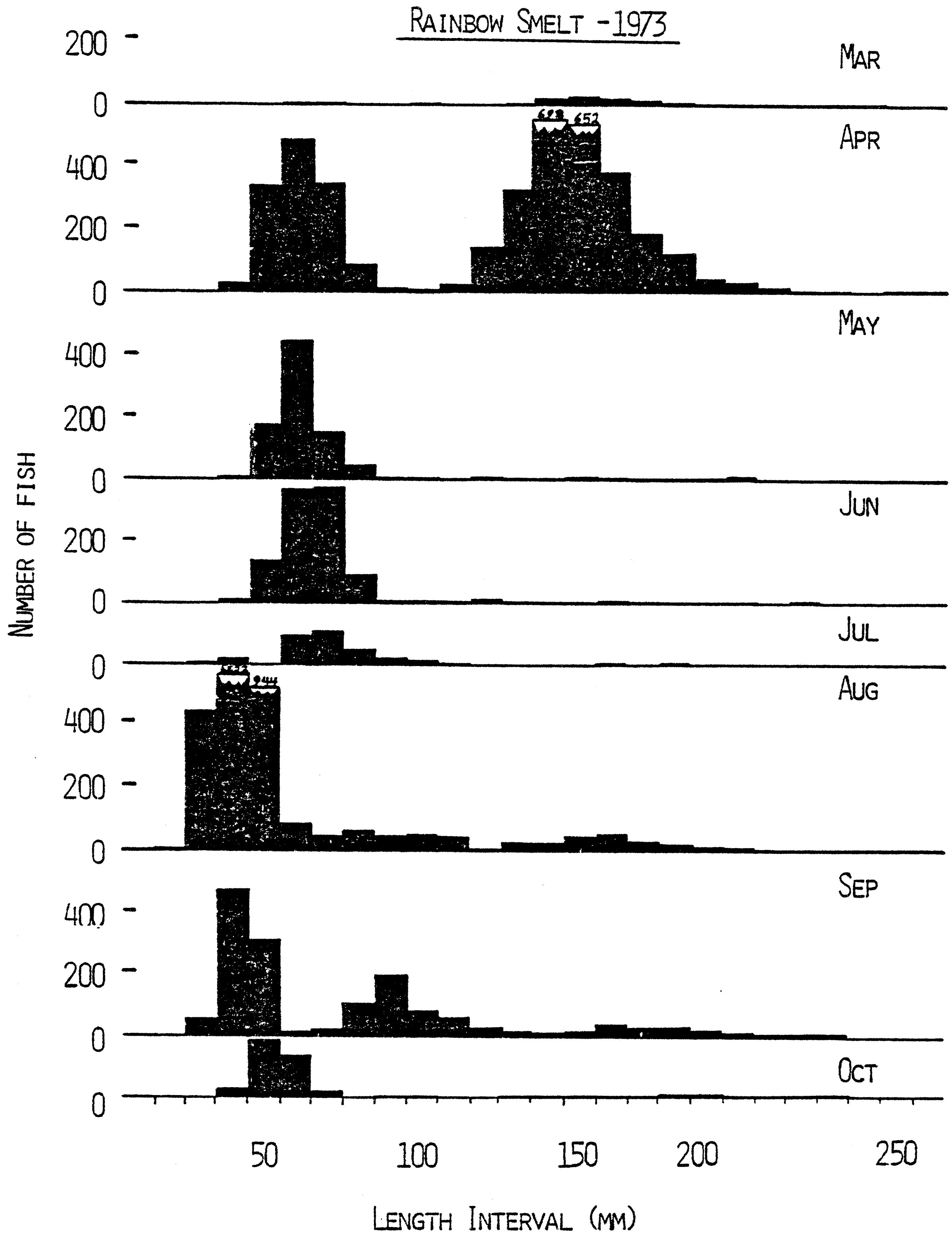


Fig. B45. Composite length-frequency histograms of all rainbow smelt collected in 1973 at Cook Plant study areas, southeastern Lake Michigan.

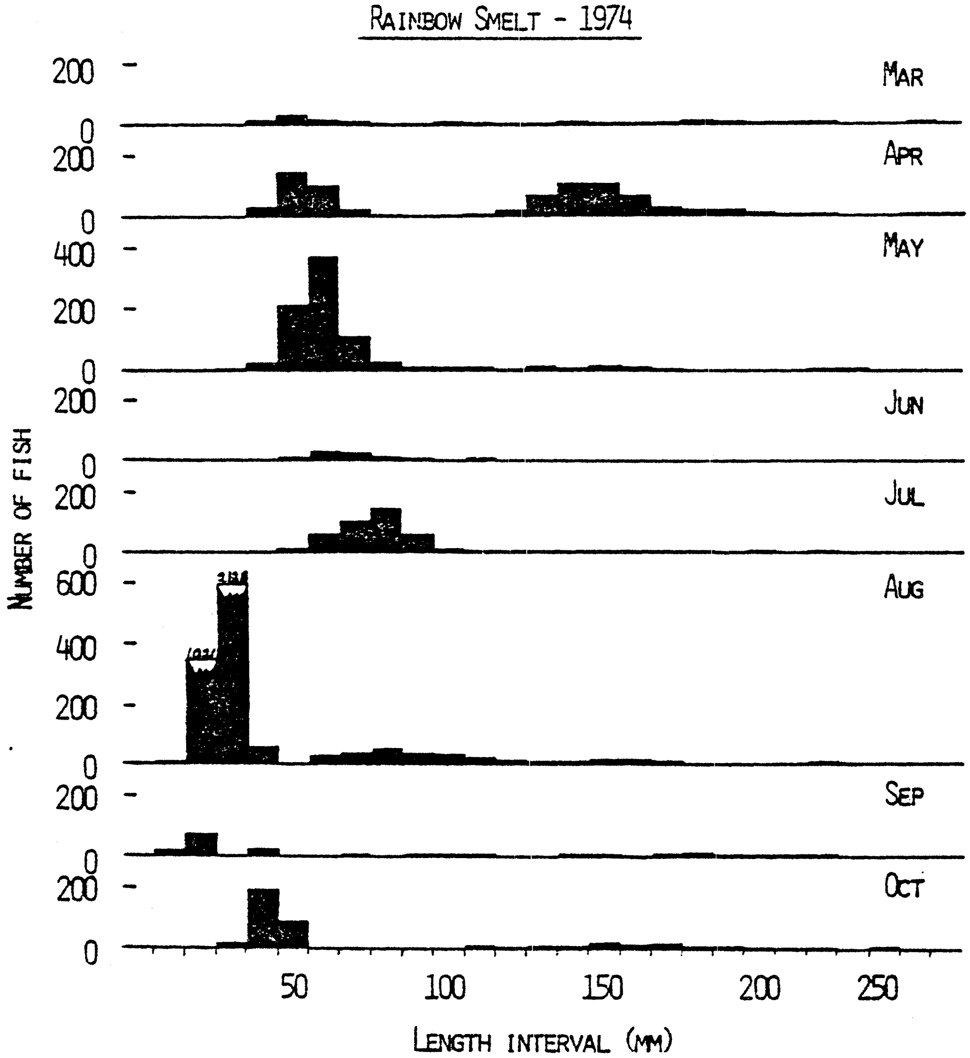


Fig. B46. Composite length-frequency histograms of all rainbow smelt collected in 1974 at Cook Plant study areas, southeastern Lake Michigan.

Yearling smelt collected in 1973 exhibited negative growth for the periods of March 15-April 28 (-0.07 mm/day) and April 28-May 17 (-0.03 mm/day). While the mean length (68 mm) of yearlings for March may have been biased because of small sample size (N=3), the sample sizes for April (N=312) and May (N=283) were large enough so as to discount biased sample size as the reason for the observed negative growth rates. No reasons can be given for the negative growth rates at this time.

The growth rate of yearling smelt increased each month over the previous month from May-October 1973 (Table B32 and Fig. B47). Only the August 22- September 20 interval varied, showing a slight decline in growth rate over the preceeding period. Maximum rate of growth (0.84 mm/day) occurred during the period September 20-October 27. By the end of October yearling smelt had attained a mean length of 126 mm for an overall growth rate of 0.26 mm/day for the 227-day period of March 15-October 27, 1973.

Table B32. Time interval (number of days in interval in parenthesis), growth increment per interval and growth rate per interval of young-of-the-year (YOY) and yearling rainbow smelt for 1973-1974 at the Cook Plant, southeastern Lake Michigan.

Year Class and Time Interval		Growth Increment (mm)	Growth Rate (mm/day)
YOY 1973			
Apr-Jul	(81)	30	0.37
Jul-Aug	(37)	4	0.11
Aug-Sep	(29)	4	0.14
Sep-Oct	(37)	9	0.24
YOY 1974			
May-Jun	(29)	12	0.41
Jun-Jul	(35)	5	0.14
Jul-Aug	(34)	14	0.41
Aug-Sep	(22)	4	0.18
Sep-Oct	(28)	10	0.36
YEARLINGS 1973			
Mar-Apr	(44)	-5	-0.07
Apr-May	(20)	-2	-0.03
May-Jun	(33)	3	0.09
Jun-Jul	(27)	8	0.30
Jul-Aug	(37)	13	0.35
Aug-Sep	(29)	10	0.34
Sep-Oct	(37)	31	0.84
YEARLINGS 1974			
Mar-Apr	(35)	1	0.03
Apr-May	(25)	5	0.20
May-Jun	(29)	3	0.10
Jun-Jul	(27)	13	0.48
Jul-Aug	(41)	14	0.34
Aug-Sep	(22)	4	0.18
Sep-Oct	(28)	31	1.11

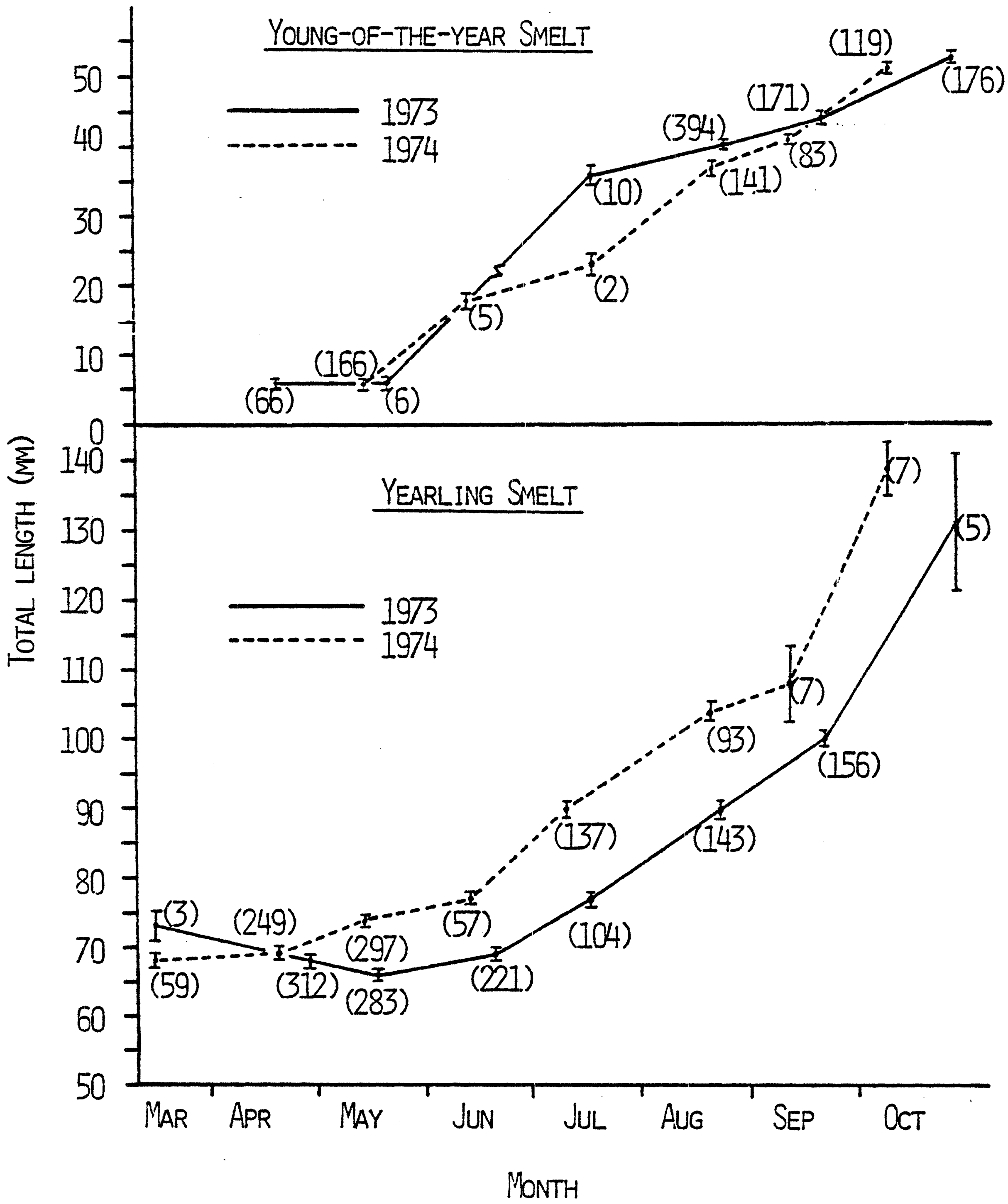


Fig. B47. Mean total length and standard error (bars) of young-of-the-year and yearling rainbow smelt collected in 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan. Lengths were taken from fish larvae, impingement and standard series fishing data. Number of observations per month are given in parentheses.

Yearling smelt collected during 1974 did not exhibit the anomalous negative growth observed for the period of March-May 1973. Growth of yearling smelt in 1974 was continuous from March-October. However, the successive increase in smelt growth rate observed each month in 1973 was not observed in 1974. As in 1973, the September-October period of 1974 was the period of greatest growth (1.11 mm/day). By early October yearling smelt had attained a mean length of 134 mm for an overall growth rate of 0.34 mm/day for the 207-day period of March 15-October 8, 1974.

YOY and yearling smelt taken in the Cook Plant vicinity from 1973-1974 had mean lengths (52 mm for YOY and 130 mm for yearling) which were less than those reported for smelt from other waters. Bailey (1964) took smelt from western Lake Superior during October-November and reported mean lengths of 66 mm and 150 mm for age 0 and age 1 smelt respectively. Burbidge (1969) collected smelt from Gull Lake and reported mean lengths for age 0 and age 1 smelt of 60.2 mm and 149.8 mm respectively. Age 1 smelt collected in Lake Michigan by Robinson (1973) from March-May 1971 at Zion, Illinois and Two Rivers, Wisconsin had mean lengths of 93.9 mm and 86.0 mm respectively. This compares to a mean length of 64 mm for age 1 smelt collected from March-May of 1973 and 1974 in the Cook Plant vicinity.

Comparison of the growth rates of YOY and yearling smelt between 1973 and 1974 indicated only a marginal difference in growth between YOY smelt but a significant difference was found for yearling smelt.

YOY smelt exhibited growth rates of 0.26 mm/day for 1973 and 0.30 mm/day for 1974. While the daily growth rate was somewhat less for 1973 compared with 1974 the increment of growth was somewhat larger for 1973 (47 mm) compared to 1974 (45 mm). The reason for the smaller daily growth rate in 1973, even though the growth increment was larger, was due to YOY smelt being taken 1 mo earlier (April) in 1973 adding 30 days to the growth period calculation.

Calculation of relative growth (Everhart et al. 1975) demonstrated the closeness of the growth rates for YOY smelt during 1973 and 1974. Relative growth was calculated from the formula:

$$\frac{l_f - l_i}{l_i}$$

where l_i was initial length and l_f was final length. The calculated values were 7.83 for 1973 and 7.50 for 1974.

Yearling smelt exhibited growth rates of 0.26 mm/day for 1973 and 0.34 mm/day for 1974, giving yearly growth increments of 58 mm and 74 mm respectively. Calculation of relative growth (0.85 for 1973 and 1.13 for 1974) for yearling smelt also showed that considerably better growth occurred in 1974 than in 1973.

It was not clear why yearling smelt grew better in 1974 than in 1973, especially since only marginal differences were observed between YOY smelt of either year. Factors which influence growth are interrelated and not easily isolated in a system as large as Lake Michigan. However, food availability and spawning success of the 1973 year class were likely contributing factors. The good spawning run experienced in 1973 coupled with the somewhat better growth of the 1973 year class, at least in comparison with the 1974 year class, may well have contributed to better growth rates of yearling smelt in 1974 compared to yearling smelt in 1973. Water temperature may also have had an effect, either directly or indirectly, since water temperatures in the Cook Plant vicinity during summer and early fall 1974 were cooler than average compared to the period of 1953-1972 (see Fig. B6).

Summary -- Smelt distribution in Lake Michigan was strictly regulated by age-class. Adults were confined primarily to deep waters (21 m and deeper) except during spawning and upwellings in nearshore areas.

YOY smelt utilized the nearshore zone (6-m and 9-m contours and perhaps beyond) as a nursery area from April through July. From August through October YOY smelt gradually moved offshore until by November they all occupied water beyond the 9-m contour.

Yearling smelt occupied the 6-m and 9-m contours in early spring and may have ranged somewhat further inshore during this time. They remained at the 6- and 9-m depths until June, at which time they started to migrate to deeper water. By October they undoubtedly began to overlap the adult population in distribution.

Temperature preference for smelt varied with age-class as did depth distribution. Adults demonstrated peak catch at 6-8 C. YOY were caught mostly at 12-14 C, while yearlings were collected most often at 10-12 C.

No large difference in growth rate was evident for YOY smelt between 1973 (0.26 mm/day) and 1974 (0.30 mm/day). There was however, a difference in growth rate for yearling smelt between 1973 (0.26 mm/day) and 1974 (0.34 mm/day). Why yearling smelt grew better in 1974 compared to 1973 is not evident, but it is likely related to the availability of food during 1974 and to the vigor of the 1973 year-class.

The pattern of growth for YOY and yearling smelt remained essentially constant between years. YOY smelt exhibited the most rapid growth during the spring while yearling smelt grew fastest in the fall.

Temporal, spatial and thermal distributions of smelt in the Cook Plant vicinity appeared to be stable between years. There appears, however, to be a large natural fluctuation in the yearly population size. We experienced a one-third decline in the 1974 smelt catch compared to 1973. Several more years' data would be necessary to accurately detail the extent of the yearly fluctuations. Overall, our preoperational data should provide a good

baseline for comparing the temporal, spatial and thermal distributions of smelt between preoperational and operational years. Any effects of the Cook Plant on the size of the smelt population will be more difficult to assess because of natural fluctuations.

Yellow Perch --

Yellow perch has been an economically important fish in Lake Michigan. Sport fishermen still put considerable effort into catching yellow perch along breakwalls and shallow areas of the lake. Commercial catches prior to 1965 were moderate to high, especially in southern Green Bay, but in the past decade production has dropped (Wells and McLain 1973). The recent lake-wide decline in perch abundance appears to be related to the increased abundance of alewives (Smith 1970). Evidently abundance of perch in Green Bay and the extreme southeastern portion of the lake never reached levels as low as those in other parts (Wells and McLain 1973). We found yellow perch to be moderately abundant in the inshore region of southeastern Lake Michigan during summer and fall of 1973 and 1974. The following is a brief summary of 1973 findings.

Although fishing efforts were very limited in winter months of 1973, five yellow perch were caught in February. Catches in spring were also low (see Table B6) revealing that only the fringes of the perch population were in the study area during winter and spring. During June, July and August catches were highest for the year. Spawning occurred in late May and early June. Catches of adults decreased during fall when perch migrated to deeper water. Young-of-the-year were first caught in July and numbers caught increased to a peak in October.

During 1973, trawling accounted for 43% of the total standard series catch (3877 fish), gillnetting - 41% and seining - 16%. The low seine catch revealed that yellow perch did not reside extensively in the beach zone during 1973. Most seined fish were caught in June (571 fish) and of these 454 were yearlings. Some YOY were seined in October.

Analysis of the 1973 trawl data suggested minimal differences between study areas (Cook and Warren Dunes). Significant seasonal distribution changes indicated large inshore migrations which commenced in May to early June. During summer most fish were inshore of 6 m. Offshore migrations began in September. Diel catches revealed crepuscular movements during summer in the study area, with inshore movements at dusk and offshore at dawn. Gill net catches also indicated these crepuscular movements. Data from gillnetting and diving observations showed perch were active during the day, but inactive at night. Analysis of the gill net data revealed no differences in abundance between the two study areas. While the above is a brief summary of 1973 findings, a more detailed discussion occurs in the 1973 report (Jude et al. 1975). The following is a discussion of 1974 data and comparisons with 1973 data on preoperational findings.

In 1974, yellow perch were the fourth most abundant species caught by standard series nets (see Table B9). Seining accounted for 74% of the total

catch, while gillnetting contributed 19% and trawling 7%. Most fish were caught by night seining (44%), while most gillnetted fish were caught during the day (14%). Day and night trawl catches were numerically similar.

Although fishing efforts during winter months were minimal, some perch were captured. Wells (1968) trawled some perch during February 1964 at 9 m in southeastern Lake Michigan. Some yellow perch were impinged during January, February and December 1974 at the Cook Plant (see SECTION E). These data indicate at least part of the perch population was present in the shallow inshore water during winter.

Numbers of yellow perch caught in spring 1974 were low (see Table B9) as they were in 1973 (see Table B6). Evidently perch do not migrate inshore in early spring to shallow warmer waters of the study area as do some other species, e.g., alewife and spottail shiner. Wells (1968) determined that adult yellow perch began moving into shallow water (6, 9 and 13 m) in late May during 1964 in southeastern Lake Michigan. Impingement data from the Palisades Nuclear Plant on Lake Michigan (44 km north of Cook) revealed that few perch were impinged until mid-May, then maximum numbers (for the period of January 1 to June 30, 1973) occurred from May 26 to June 8 (Consumers Power Company 1973b). Brazo et al. (1975) found most perch were in deep water (24 m) during early April 1972 in central Lake Michigan. They also found that on May 21, migration of male perch into shallow water (6-12 m) occurred when water temperatures had reached 6-7 C. Interestingly these temperatures are usually reached in our area during April (see Figs. B3-5), but few adults were caught during April and May of both years. We have no reason to suspect that inshore migrations would occur later in our area when water temperatures are warmer. Although our impingment data for 1973 and 1974 are sporadic as a result of plant testing, preliminary data for 1975 showed that few adult perch were impinged until June. These data lead us to believe that yellow perch do not migrate in early spring to the study areas to spawn, but probably move to other areas of southeastern Lake Michigan. Probably the lack of extensive rocky substrate and aquatic plants in our area constitutes unsuitable spawning habitat for yellow perch.

Abundance of perch during June sampling was still low. Low catches in June 1974 contrasted sharply with June 1973 high abundances. Spawning occurred in late May and early June during 1974 (Table B33) as it did in 1973. Low catches of adults in May and June 1974 again indicated that spawning was not extensive in the study areas. Supplementary gill net sets at 6 and 9 m on June 1, 1974, which was very near the time of spawning, produced very few adult perch. Larval catches of yellow perch in 1973 were very low (12 fish, see Jude et al. 1975). Most were caught on June 18-19. During 1974, when more effort was put into larvae sampling, only 88 perch larvae were caught, the vast majority (86) of these on June 11-12 (see SECTION C). The size and time of capture of these larvae again demonstrated that the majority of spawning occurred during late May and early June of both years. The small size of some of these larvae indicated the possibility that some were hatched in the study area, although movement of planktonic larvae via strong currents may have transported these fish into

Table B33. Monthly gonad conditions of yellow perch as determined by inspections and classification of the state of development of ovaries ant testes. Fish were captured during 1974 in southeastern Lake Michigan. All fish in a month were included except poorly received specimens.

Gonad condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Females						
Poorly dev.	5	1		10	10	51	183	139	81	2	31	23
Mod. dev.	6		5	1		8	4	39	26		12	5
Well dev.	2		3	9	3	4					5	1
Ripe-running												
Spent						59	153	74	48	1		
						Males						
Poorly dev.	3		2	7	1	19	121	111	106	2	1	14
Mod. dev.	3		9	9	4	11	11	46	42	3	12	23
Well dev.			3	25	6	15	3	3		4	49	2
Ripe-running					2	1						
Spent						6	53	46	41	2		
						Unable to distinguish						
						3	45	6	1	1		1
						Immature						
	36	10	41	15	28	37	108	49	23	10	7	13

the area. Some spawning (we suspect very little) does occur in the study area. Divers found one strand of yellow perch eggs with eyed embryos among the riprap around the intake structures on June 25, 1975. Apparently riprap around the intake and discharge structures has afforded yellow perch a suitable substrate for spawning, although the size of the area probably precludes any extensive spawning.

Data from the literature revealed that yellow perch spawn when temperatures reach 8.9-12.2 C in the spring (Scott and Crossman 1973). These temperatures are usually attained during May in the study area (see Fig. B3). Apparently spawning in southeastern Lake Michigan occurs when inshore temperatures are in the 11-12 C range, as these temperatures occurred in late May and early June during 1973 and 1974 (see Figs. B4 and B5).

Catches in July and August 1974, were high (see Table B9) with most of the fish being seined yearlings. Numbers of perch caught in September dropped considerably from summer peaks and by October most perch had left the shallow inshore waters. Apparently there was some fall and winter movements of perch between intermediate and shallow depths. Impingement data (see SECTION E) showed that some perch were inshore, especially during December when many YOY were impinged.

Statistical analysis --

Trawls -- As a result of very low catches in April and May the ANOVA was only used to test differences in catches from June through October, 1973 and 1974. Testing of assumptions (normality and variance homogeniety) of the ANOVA gave marginal significance (see SECTION A). Results of the test revealed several significant interactions which confounded interpretation of main effects (Table B34). These factors -- shortened data base (5 mo instead of 7), marginal significance of ANOVA assumption tests and significant interactions, all contributed to reducing the interpretative value of the ANOVA results. The following discussion will be a subjective analysis of the data emphasizing major changes and possible causes corroborated by the statistical results.

The most outstanding change in the 2 yr trawling data was an 81% decline in total catch during 1974 (1661 fish in 1973, 313 in 1974). ANOVA results showed the difference between mean catches in the 2 yr was highly significant (Table B34). Catches from June through October were consistently higher in 1973 (Fig. B48). Because generally all size classes (except yearlings) were caught in lower numbers during 1974 (see Seasonal distribution by age-size class) we can conclude that this yearly variation was not a result of a population structure change (e.g. a dominant year class). We can only conjecture that generally warmer temperatures during summer 1973 (see Fig. B6) caused a greater abundance of perch in the study area. This hypothesis is somewhat tenuous because average temperatures during September of both years were similar yet catches were still high in 1973 (bottom temperatures during trawling were higher in 1974). Obviously extreme abundance changes as this are not uncommon in the

Table B34. Summary of analysis of variance for yellow perch caught in trawls at Cook Plant study areas from June through October 1973 and 1974.

Source of variation	df	Adjusted mean square[1]	F-statistic
YEAR	1	18.27115	144.28**
MONTH	4	.91796	7.25**
AREA	1	.13850	1.09
DEPTH	1	1.11598	8.81*
TIME	1	.20256	1.60
YxM	4	.43293	3.42
YxA	1	.18801	1.48
MxA	4	.25777	2.04
YxD	1	.54922	4.34
MxD	4	1.20413	9.51**
AxD	1	.00778	.06
YxT	1	.02786	.22
MxT	4	1.88542	14.89**
AxT	1	.34018	2.69
DxT	1	.02641	.21
YxMxA	4	.16004	1.26
YxMxD	4	.33681	2.66
YxAxD	1	.17757	1.40
MxAxD	4	.06565	.52
YxMxT	4	1.29169	10.20**
YxAxT	1	.15477	1.22
MxAxT	4	.13570	1.07
YxDxT	1	.10624	.84
MxDxT	4	.03649	.29
AxDxT	1	.31966	2.52
YxMxAxD	4	.18932	1.50
YxMxAxT	4	.23758	1.88
YxMxDxT	4	.09964	.79
YxAxDxT	1	.11729	.93
MxAxDxT	4	.15976	1.26
YxMxAxDxT	4	.06754	.53
Within cell error	79[2]	.12663	

** Significant ($P < .001$).
 * Significant ($P < .01$).

1 Mean squares were multiplies by harmonic cell size/maximum cell size ($n_h/N = .9877$) to correct for 1 missing observation where the cell mean was substituted.

2 One degree of freedom was subtracted to correct for 1 missing observation where the cell mean was substituted.

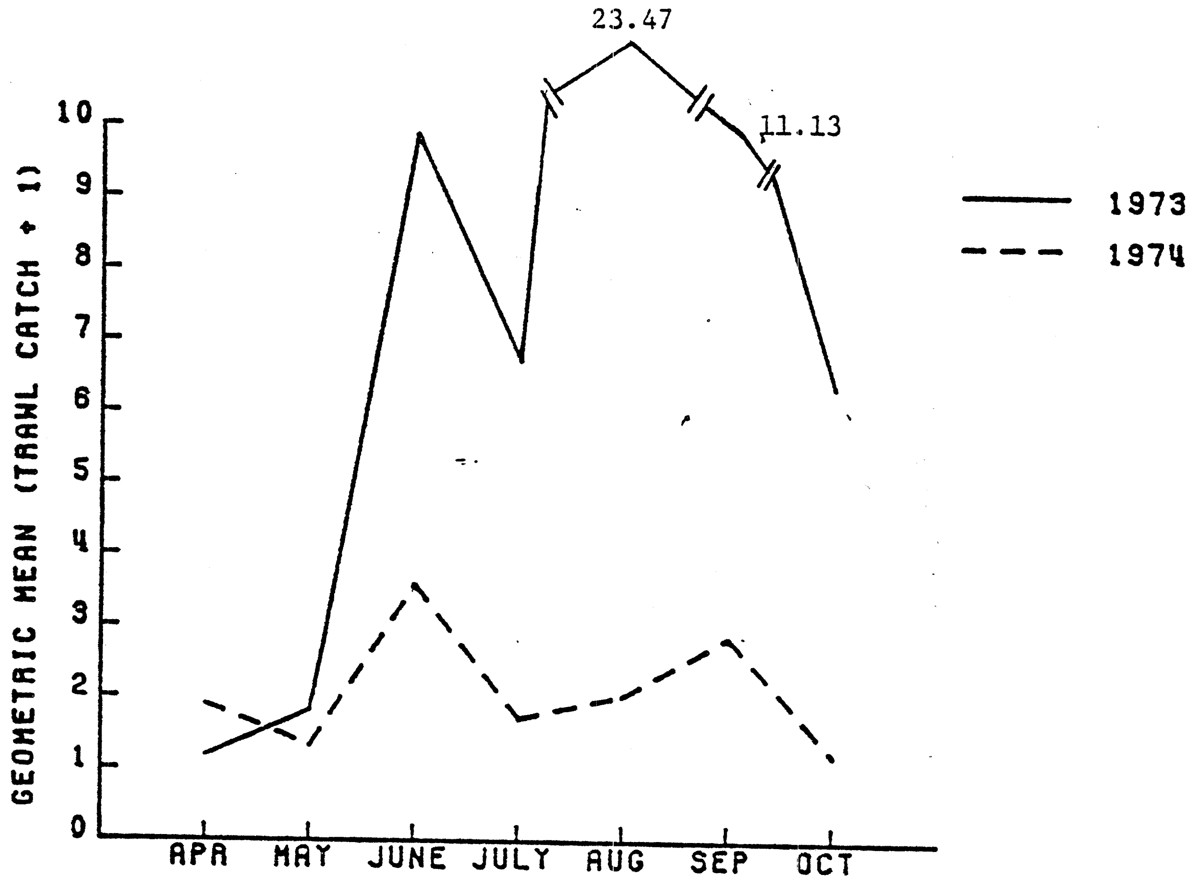


Fig. B48. Geometric mean number of yellow perch caught in duplicate trawl hauls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

study area.

The ANOVA for 1974 showed no significant difference in mean catches between the two areas, Cook and Warren Dunes (Table B34). Data for 1973 alone also showed no significant difference (Table B23, Jude et al. 1975). This finding for the two preoperational years establishes Warren Dunes as a valid control. Operational statistical comparisons can now be made between the two areas to determine any possible plant operational effects on perch abundance in the Cook Plant area.

Two trends in perch distribution found in 1973 data were also observed in 1974 data and contributed to the significance of MONTH and DEPTH in the ANOVA and interactions of MONTHxDEPTH and MONTHxTIME (Table B34). During spring (April and May) and fall (September and October) night catches of perch were higher than day catches, while in summer, day catches were higher than night catches (Fig. B49). Catches at the two trawling depths also revealed a spring-fall and summer pattern (Fig. B49). During spring and

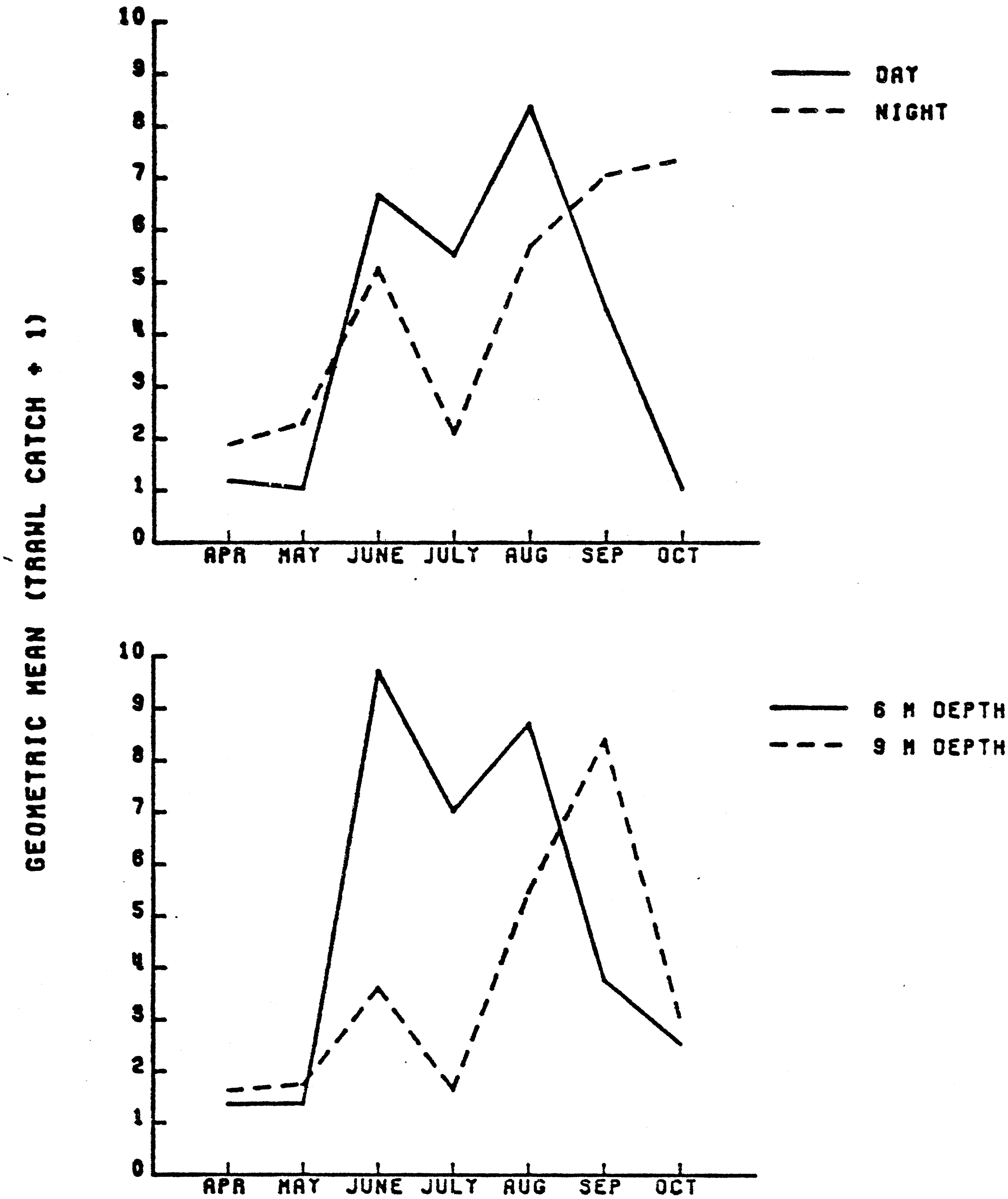


Fig. B49. Geometric mean number of yellow perch caught in duplicate trawl hauls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

fall, catches were generally greater at 9 m while in summer 6-m catches were higher.

These two patterns were the result of three types of movement or activity: increased diurnal activity, inshore-offshore movements and seasonal location of the population. In spring and fall most of the perch population was deeper than 9 m; however it appears that YOY and yearlings were at depths shallower than 9 m during fall (see Young-of-the-year and Yearlings). At dusk yellow perch moved inshore thereby increasing night catches especially at 9 m (Fig. B49). During summer most of the local population was at 6 m or less. Day catches of perch were higher than night catches because of increased day activity and the inshore movement at dusk. Divers found yellow perch to be inactive at night (Dorr 1974b, Dorr and Miller 1975). Inshore movements at dusk (Hasler and Bardach 1949) and increased diurnal activity (Hergenrader and Hasler 1966) have been noted for yellow perch in Lake Mendota, Wisconsin. Scott (1955) also found these two activities for yellow perch in Rondeau Bay, Lake Erie.

While some information on perch movements has been obtained from our standard series trawl and gill net data, one series of short period supplemental gill net sets during July 1973 revealed additional information on diel movements. Catches from these nets demonstrated that perch were inactive nocturnally (2300-0415) at depths of 6 and 9 m (Table B35). Low catches at 9 m between 1815-2230 were probably the result of low abundance. Evidently during the day some perch moved out to 9 m (probably as a result of foraging activities) where they were most abundant at 1415-1615. The high catch at 6 m between 1815-1945 indicated that just before sunset (sunset was approximately 2030 on this date) fish moved into 6 m and probably shallower depths. Nets fished near sunrise (approximately 0515)

Table B35. Number of yellow perch caught in gill nets set for various periods at two depths on July 3 and 4, 1973 at the Cook Plant study area, southeastern Lake Michigan.

Time period nets were set	Diel Period	Number of yellow perch caught per hour	
		6-m station (C)	9-m station (D)
1415-1615	Day	27	82
1615-1815	Day	28	14
1815-1945	Day	65	1
2000-2230	Sunset at 2030	17	2
2300-0415	Night	1	1
0515-1530	Sunrise at 0515	21	13

were set too long (0515-1530) to reveal if a sunrise offshore migration (from depths of <6 m to 9 m) occurred. A sunrise offshore movement of yellow perch has been found by others (Hasler and Bardach 1949, Bardach 1955, Scott 1955 and Engel and Magnuson 1976) and we suspect it occurs in our study area.

In summary, the ANOVA test revealed considerable variability in preoperation trawl catch data. This variability was a result of the perch population not permanently residing in the study area, but migrating into the area only in summer and moving through the trawling depths with nocturnal inshore and diurnal offshore movements. The ANOVA also showed that statistically significant changes in abundance occur from year to year, undoubtedly the result of meteorological variability. These findings indicate it will be very difficult to statistically substantiate any possible plant induced effects on perch abundance and distribution. Fortunately the nonsignificance of differences between AREA catches will help define major changes which might occur at the Cook area during operational years.

Gill nets -- Results of paired analyses using the nonparametric Wilcoxon and Median tests revealed very few significant differences (Table B36). Both tests showed TIME was a significant factor during 1973, with day catches higher than night catches at the 9-m Cook station and 6-m Warren Dunes station. The Median test also revealed two significant differences in DEPTH and AREA with 9-m day catches greater than 6-m day catches at Cook during 1973 and day catches at 9 m greater at Cook than at Warren Dunes during 1974. These significant differences with TIME were consistent with movements and activities of yellow perch established by trawl catches (see Trawls). Again, higher day than night catches showed the decreased nocturnal activity of perch.

While the Median test showed a statistically significant difference in the DEPTH factor during 1973, the Kruskal-Wallis test used on the 1973 gill net analysis (p. 134 in Jude et al. 1975) did not show this DEPTH difference, but this may have been a result of monthly differences obscuring this effect (see SECTION A). In contrast to this gill net finding of no difference between depths, trawling data generally revealed greater catches at 6 m than 9 m (especially in summer). While the trawl does not catch many large perch, gill nets do; therefore, gill net data are more indicative of larger perch movements. Possibly day gill nets at 9 m are collecting more perch because of inshore/offshore movements. Also, larger fish may not be as abundant in shallower depths (6 m to shore) but are in deeper water than smaller perch which are effectively sampled by the trawl.

The significant difference between AREA's (Table B36) during 1974 is in contrast to 1973 when no differences were indicated by the tests. Evidently yellow perch were more abundant at the Cook 9-m area than at the 9-m Warren Dunes area in 1974. The cause for this abundance change between years is unknown. But in view of the extreme variation in trawl catches between

Table B36. Results of Wilcoxon and Median (Sign) tests of paired comparisons of standard series gill netcatches of yellow perch in Cook Plant study areas, southeastern Lake Michigan during 1974 and 1974. Factors were Year, Area, Depth and Time with comparisons in the table given in the same order. Tests were conducted at $\alpha = .10$. NS = Nonsignificant; NT = No test, insufficient non-zero differences.

TEST	TEST RESULTS							
YEAR	Cook Plant				Warren Dunes			
	6M		9M		6M		9M	
	day	night	day	night	day	night	day	night
Wilcoxon	NS	NS	NS	NS	NS	NS	NS	NS
Median	NS	NS	NS	NS	NS	NS	NS	NS
AREA	1973				1974			
	6M		9M		6M		9M	
	day	night	day	night	day	night	day	night
Wilcoxon	NS	NS	NS	NS	NS	NS	NS	NS
Median	NS	NS	NS	NS	NS	NS	Cook>Dunes	NS
DEPTH	1973				1974			
	Cook Plant		Warren Dunes		Cook Plant		Warren Dunes	
	day	night	day	night	day	night	day	night
Wilcoxon	NS	NS	NS	NS	NS	NS	NS	NS
Median	9M>6M	NS	NS	NS	NS	NS	NS	NS
TIME	1973				1974			
	Cook Plant		Warren Dunes		Cook Plant		Warren Dunes	
	6M	9M	6M	9M	6M	9M	6M	9M
Wilcoxon	NS	day>night	day>night	NS	NS	NS	NS	NS
Median	NS	day>night	day>night	NS	NS	NS	NS	NS

years this type of change is apparently not uncommon in the inshore areas of southeastern Lake Michigan. During 1973, more perch were gillnetted at Cook than Warren Dunes (898 vs. 692), while in 1974 slightly more were caught at Warren Dunes (461 vs. 402). These 1974 numbers represent a 46% decline in gillnetted perch over 1973 catches. Although not as drastic a decline as the trawling catch (81%), gill net catch data support the overall decline in abundance between years at the study areas.

As in 1973, monthly catches during 1974 showed considerable variation in numbers (Fig. B50). Catches during 1974 were low from January through June, increased in July and then peaked in August and September. Very small catches occurred in October and December, while November catches were moderate. Similar seasonal trends were found in 1973 with low winter and spring catches, peak catch in summer and moderate to low catches in fall. Two obvious differences between years were the June (high in 1973, low in 1974) and September (low in 1973, high in 1974) catches. Evidently the summer concentration was 1 mo earlier in 1973. Possibly warmer temperatures during summer (see Fig. B6) caused fish to concentrate earlier in 1973.

Seines -- Parametric statistical tests were not performed on seine data because assumptions of the tests were not met by the transformed data. Nonparametric tests were also not used because of too many zero catches. The following discussion is a qualitative subjective analysis of the 1973 and 1974 seine data without significant differences being confirmed with statistical procedures.

During 1974, yellow perch (mostly yearlings, see Seasonal distribution by age-size class) were abundant in the beach zone only during July and August (Fig. B51). This finding is in contrast to 1973 when perch were only abundant during June (see Fig. B29 in Jude et al. 1975). The exact reason for this yearly variation is unknown, but warmer monthly temperatures during summer 1973 (especially June, see Fig. B6) may have caused perch to concentrate in the beach zone earlier in 1973 than in 1974.

While few major differences were found among catches at the three seining stations in 1973, during 1974 catches were somewhat different. Large catches occurred day and night in August at beach station B (S Cook), but not at stations A (N Cook) (night catches were moderate) and F (Dunes) (Fig. B51). Unusual catches of spottail and emerald shiners also occurred at station B (see Spottail Shiner and Emerald Shiner). Evidently some fish species were attracted to station B more than the other stations, probably because of the physical bottom characteristics at station B (see Spottail Shiner).

When peak abundance of yellow perch occurred in 1973 and 1974, night catches were higher than day catches at beach stations A (N Cook) and F (Warren Dunes), but the opposite occurred at station B (S Cook). Gill net and trawl data indicated that perch moved inshore at dusk, therefore we would have expected large seine catches at night because of greater abundance and less net avoidance. Catches at beach stations A and F

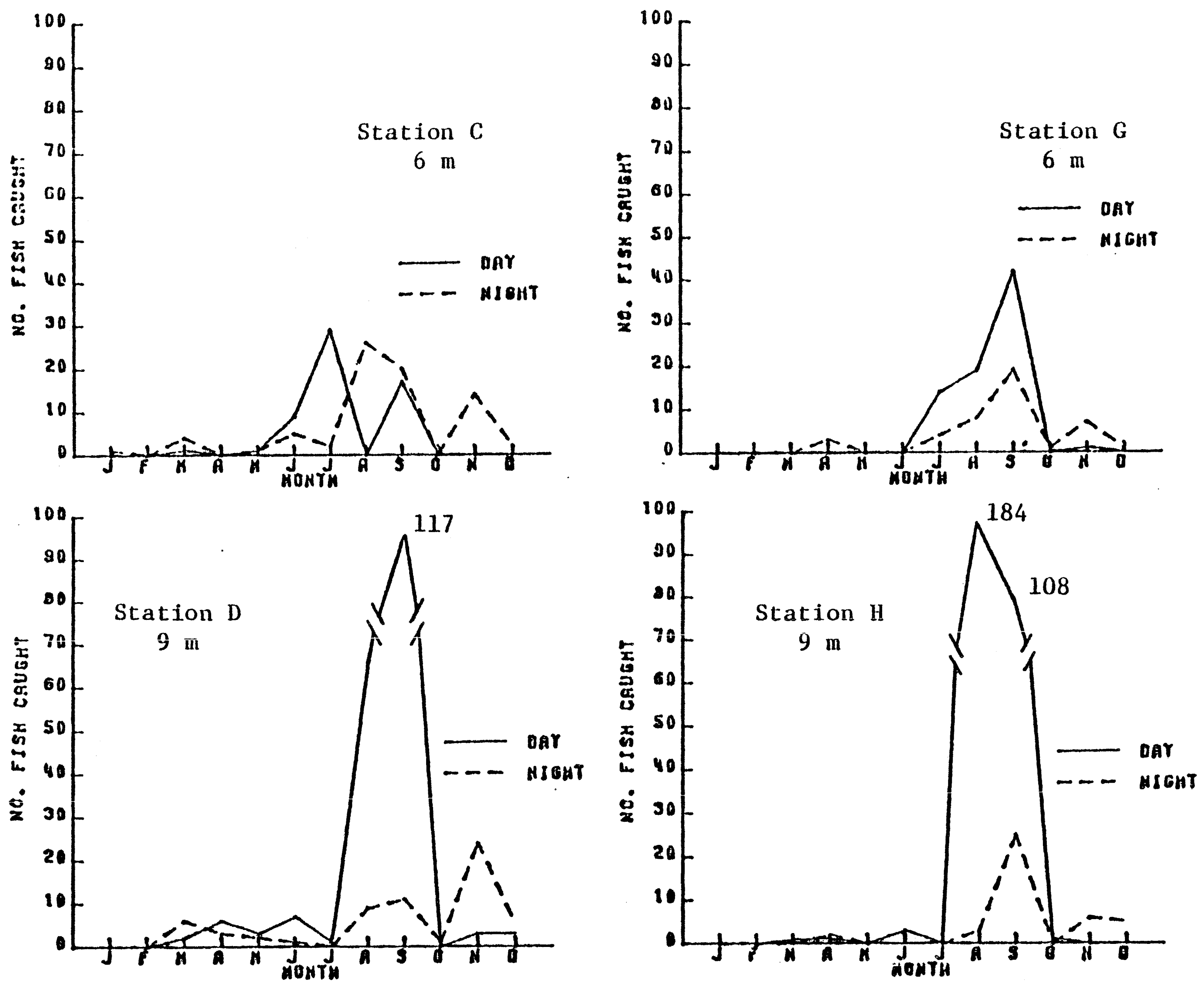


Fig. B50. Numbers of yellow perch caught in standard series gill nets during 1974 at four stations in the Cook Plant study area, southeastern Lake Michigan.

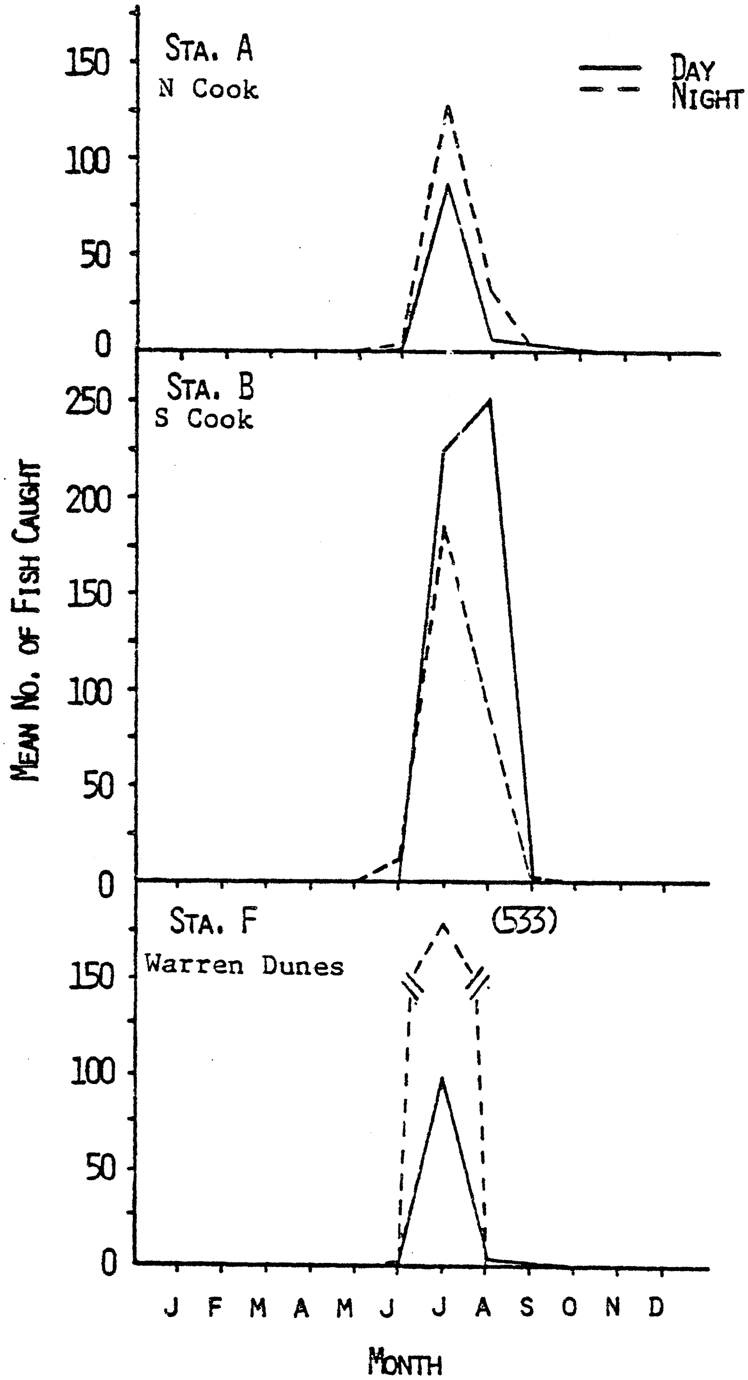


Fig. B51. Mean number of yellow perch caught in duplicate standard series seine hauls at three stations in Cook Plant study areas, southeastern Lake Michigan.

confirmed this pattern, but perch were more abundant at station B during the day. Again, this day and night anomaly at station B may be a result of the atypical physical characteristics of this station. These characteristics may attract perch to the area during the day, but at night the fish move to other areas. Some of the catch variability may also be a result of schooling behavior causing contagious distributions. Schooling behavior by yellow perch has been well documented (Hergenrader and Hasler 1967, 1968; Nursall and Pinsent 1969; Nursall 1973 and Emery 1973). We also observed (via snorkling) schooling by yearling yellow perch in the beach zone during August 1975 at station F (Warren Dunes).

Seasonal distribution by age-size class -- Without exact age data, we can only differentiate three age-size classes from length-frequency data. Length-frequency histograms of yellow perch caught in standard series nets were compiled by gear type (Figs. B52 - B54). The following discussion will concentrate on three groups: young-of-the-year (YOY), yearlings and adults (age 2 +). Adult is an arbitrary classification because sexual maturity is usually not achieved by males until 3 yr and females at 4 yr of age (Scott and Crossman 1973); although Brazo et al. (1975) found almost all perch older than age 1 were mature in central Lake Michigan.

Young-of-the-year -- In 1974, YOY (38 fish) were first caught by trawling and beach seining during August (Figs. B52 and B54). Mean length of these fish was 43 mm $\pm$ 4 (SD). Most (86) yellow perch larvae (total of 88 caught) were caught during June when their mean length was 6.0 mm $\pm$ 0.5 (SD). Therefore between June and August YOY grew 0.6 mm/day. Rate of growth (0.4 mm/day) declined slightly between August and September. From September to October rate of growth was also 0.4 mm/day. During the last 3 wk of October and through December very little growth occurred. The rate from October to November was 0.03 mm/day and from November to December it was 0.1 mm/day.

While field catches of YOY declined steadily from August to December, impingement data revealed some YOY were present near the intake structures during all of these months. After October no YOY were seined, demonstrating that this life stage resides outside the beach zone after October. Because fishing effort was minimal during November and December (no trawling occurred except for night trawls in November) we may have missed sampling YOY perch in the area. YOY perch were impinged during November and December, which indicates that at least some of the YOY population remains inshore during early winter. Impingement data from the Palisades Nuclear Plant on Lake Michigan (44 km north of Cook, intake at 6 m) showed that some YOY perch were impinged during November and December, 1972 (Consumers Power Company 1973a). During 1975 we trawled in December and some YOY were collected, especially during the day at 9 m. Evidently in our area during colder months the bulk of the YOY population remains in water deeper than 9 m, but the fringes of the population are at 6-9-m depths and some individuals may migrate into these waters during the day. Our data and Palisades' data would lead us to conclude that during colder months YOY perch in southeastern Lake Michigan remain at depths slightly deeper than

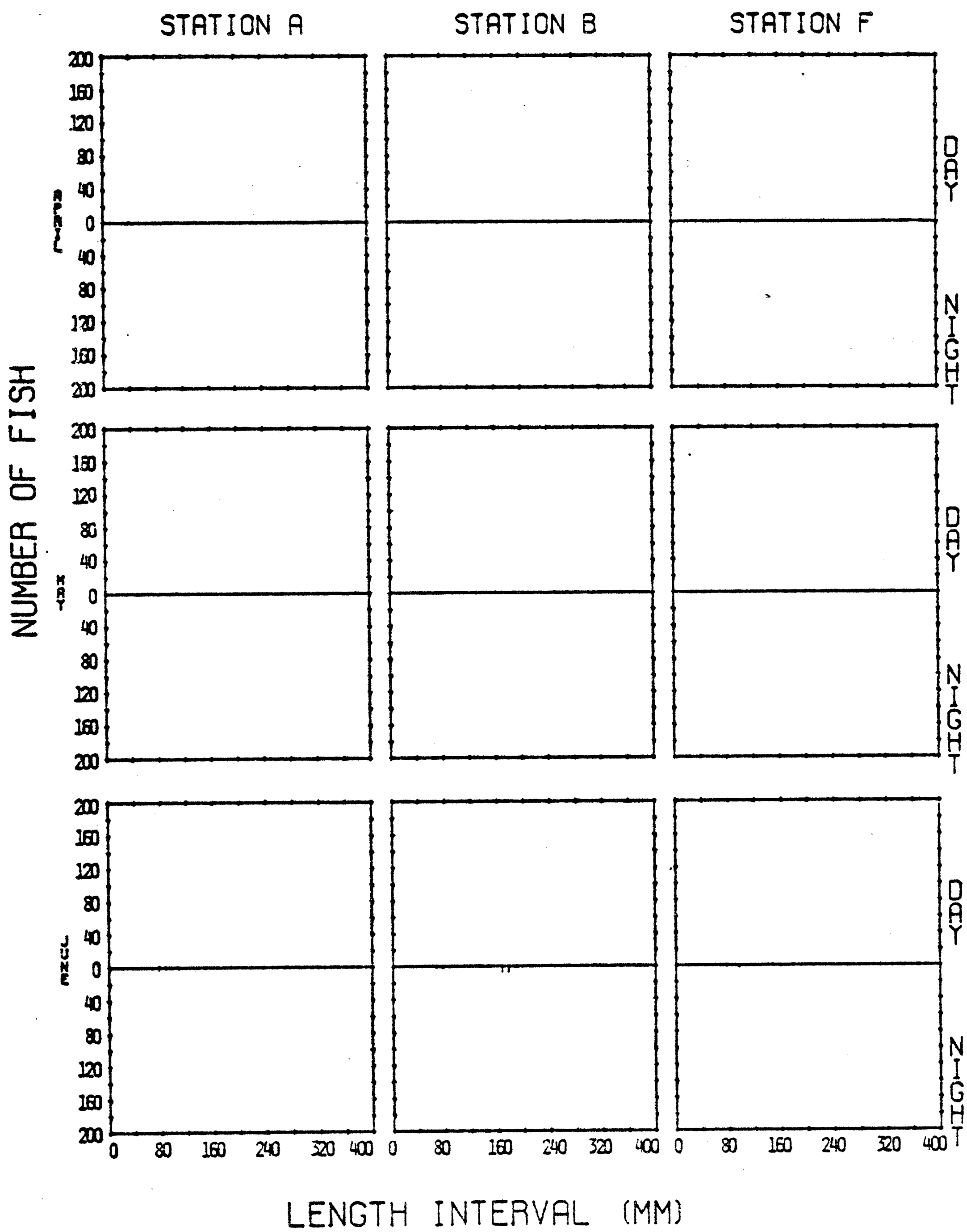
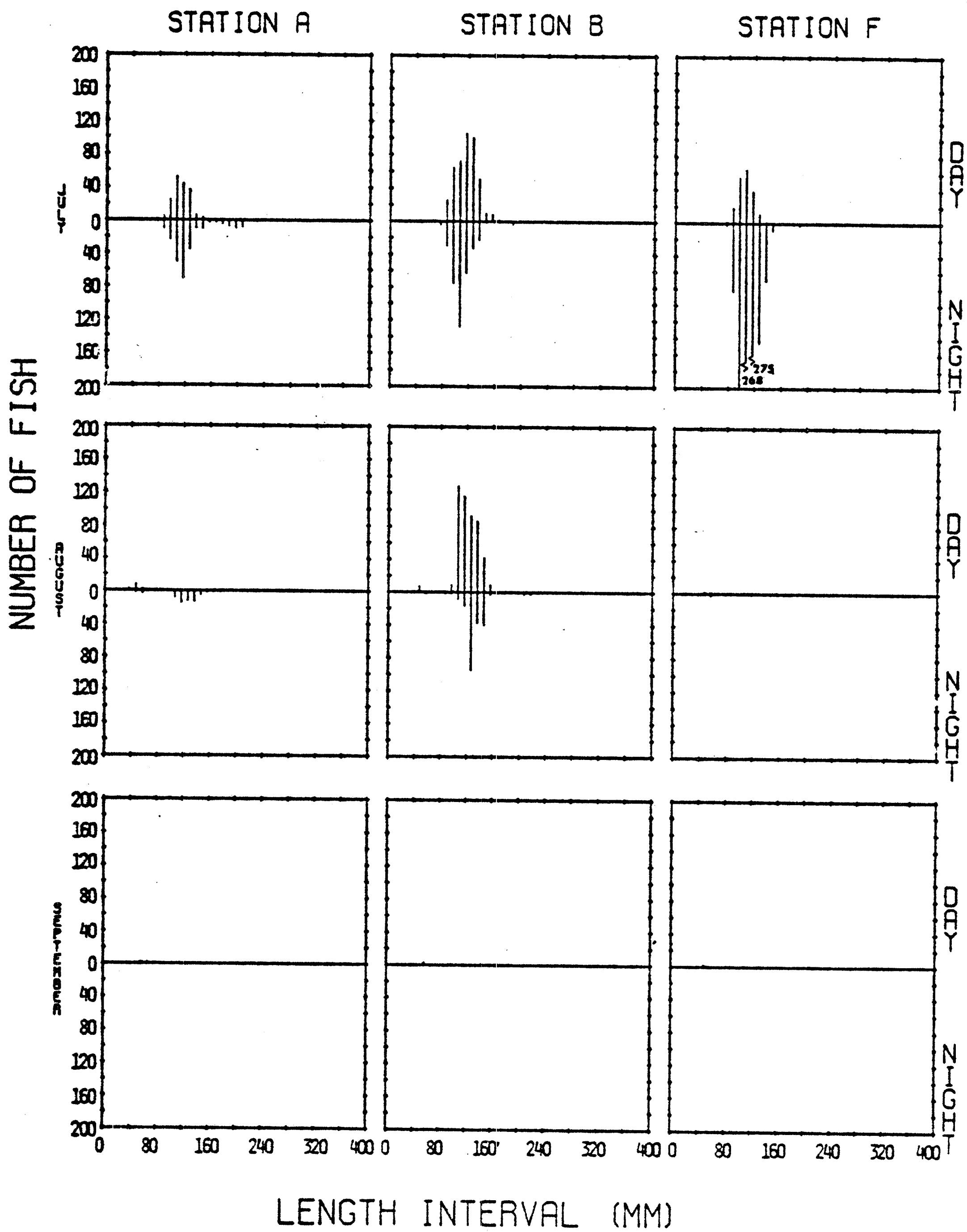


Fig. B52. Length-frequency histograms for yellow perch caught by standard series seining during 1974 at Cook Plant study areas, southeastern Lake Michigan.



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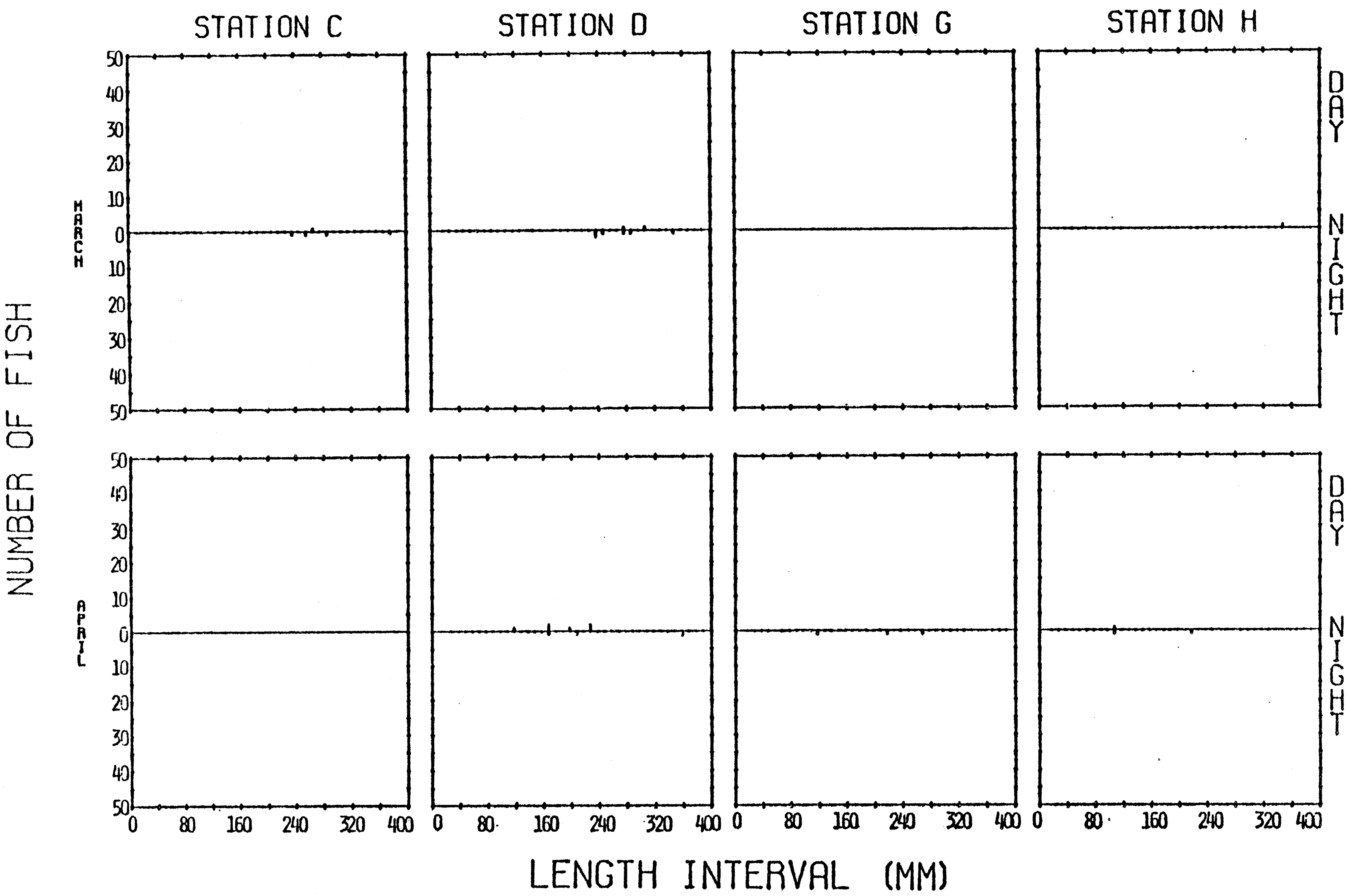
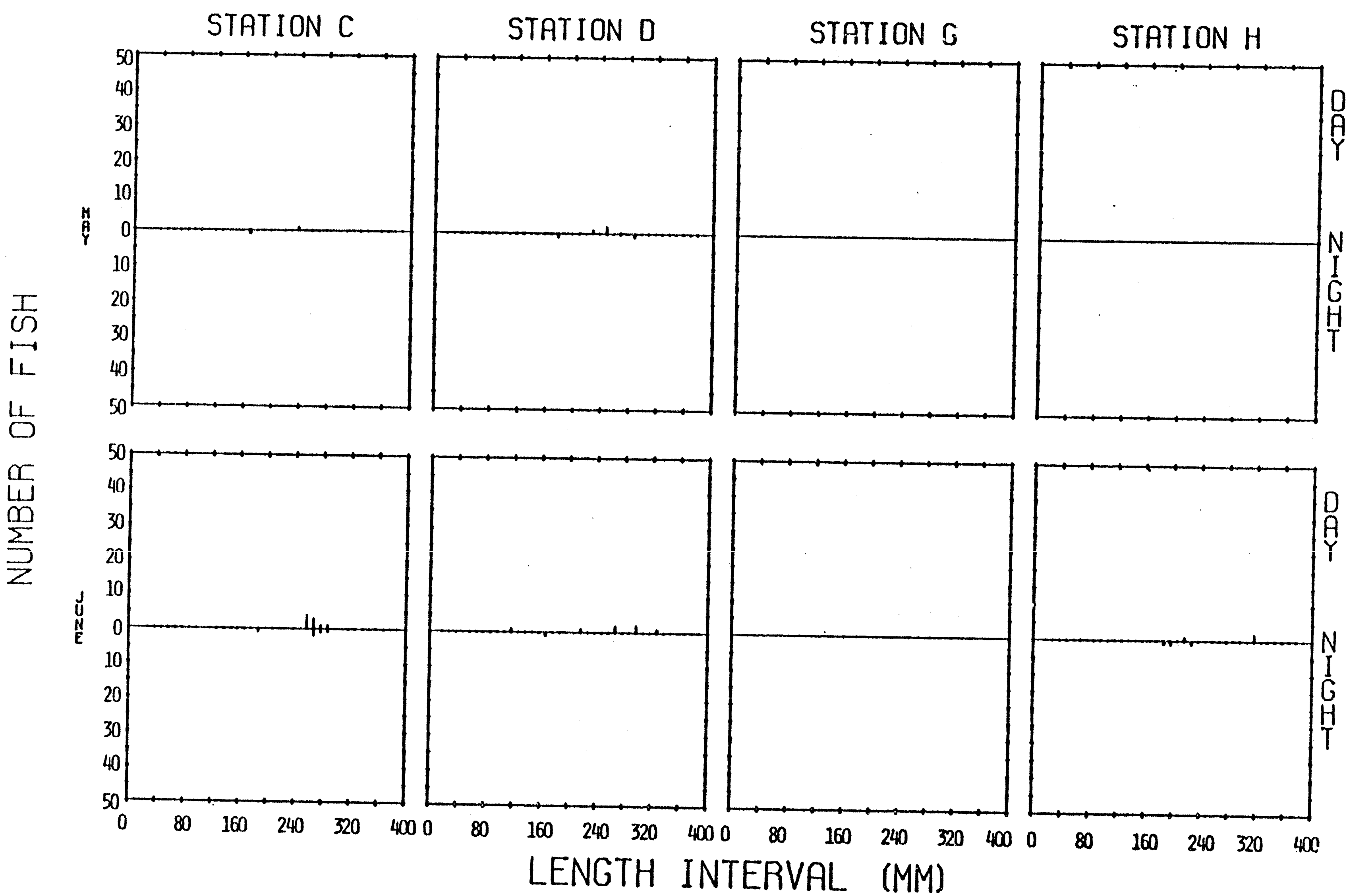


Fig. B53. Length-frequency histograms for yellow perch caught by standard series gillnetting during 1974 at Cook Plant study areas, southeastern Lake Michigan.



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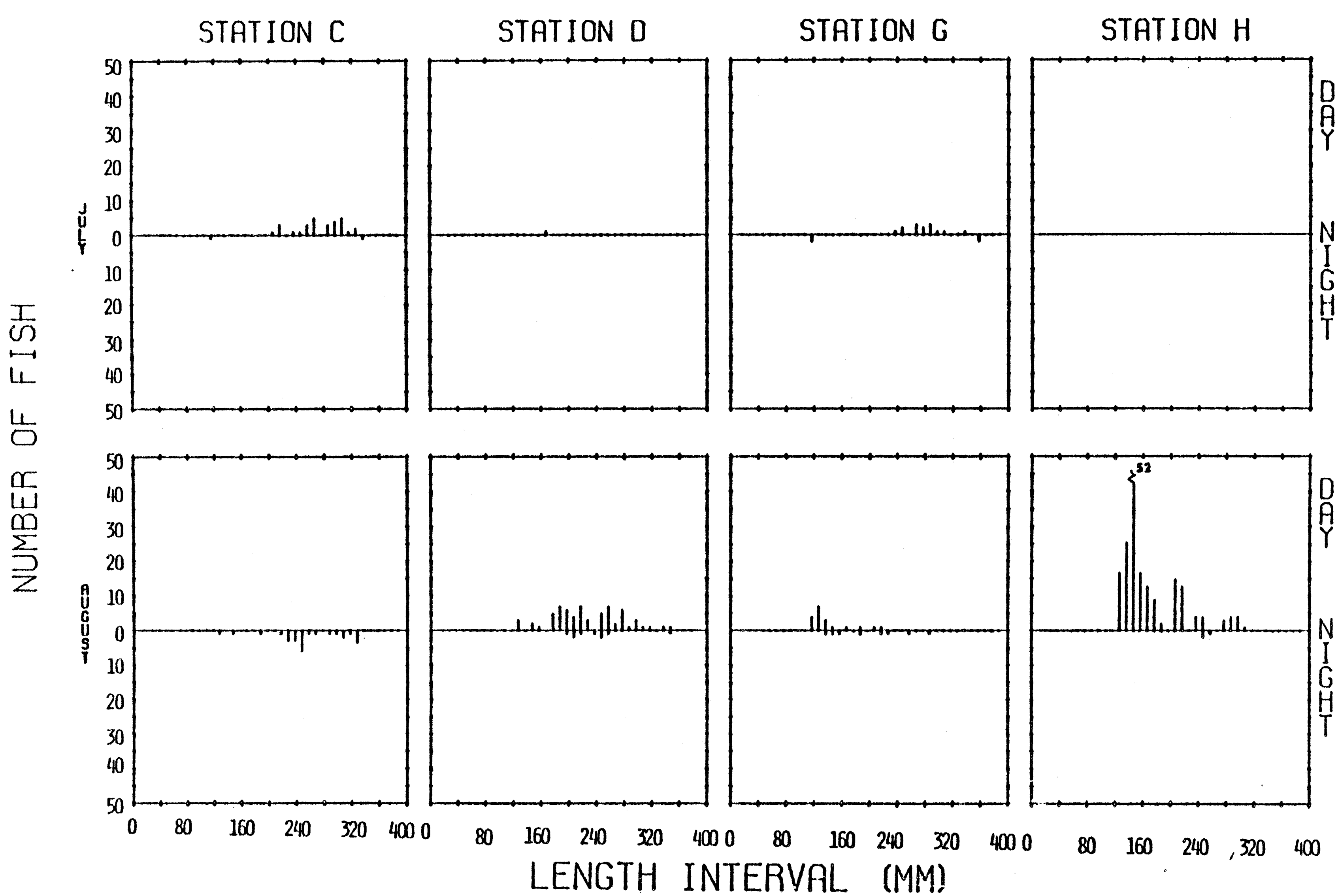

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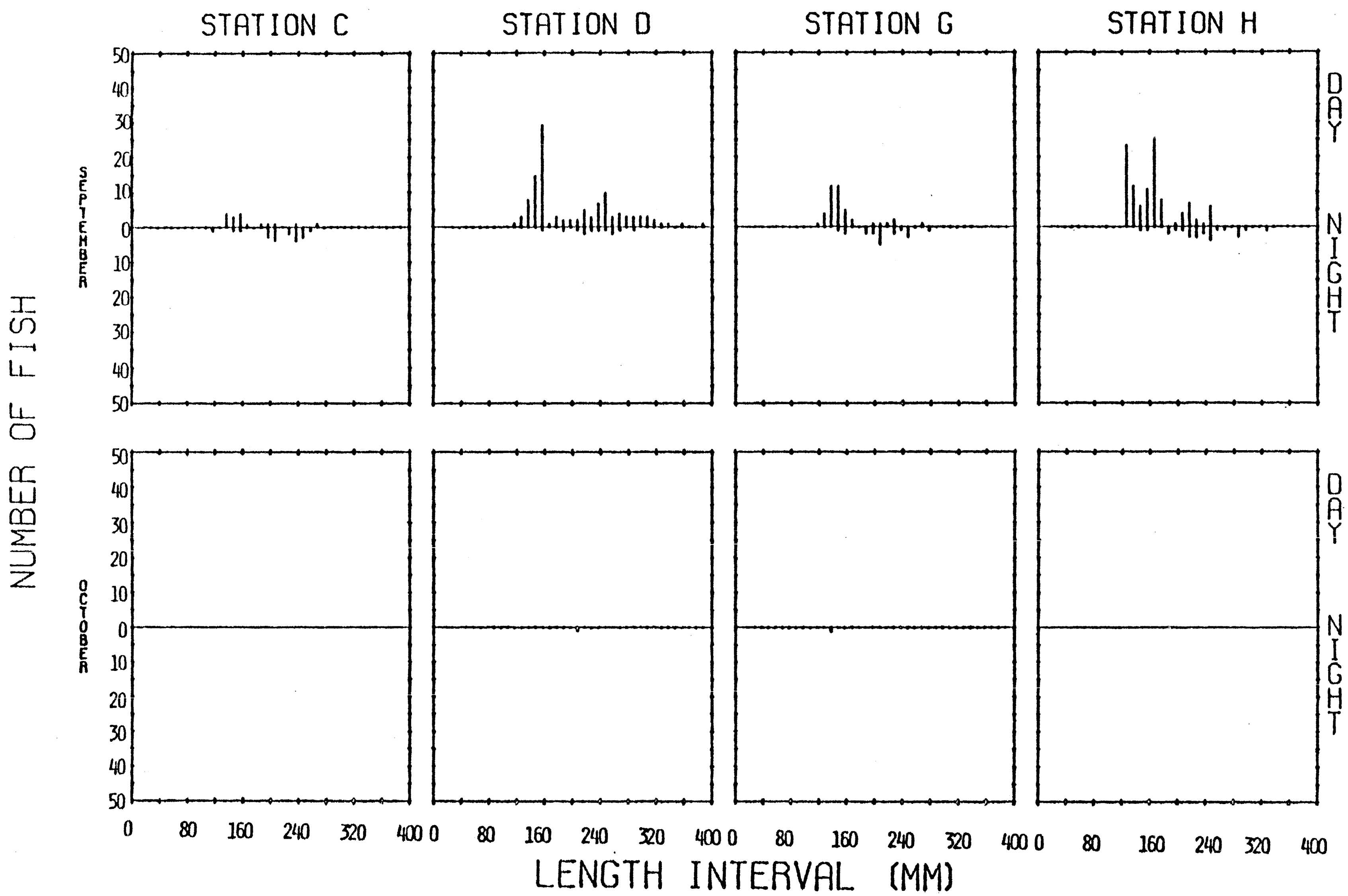

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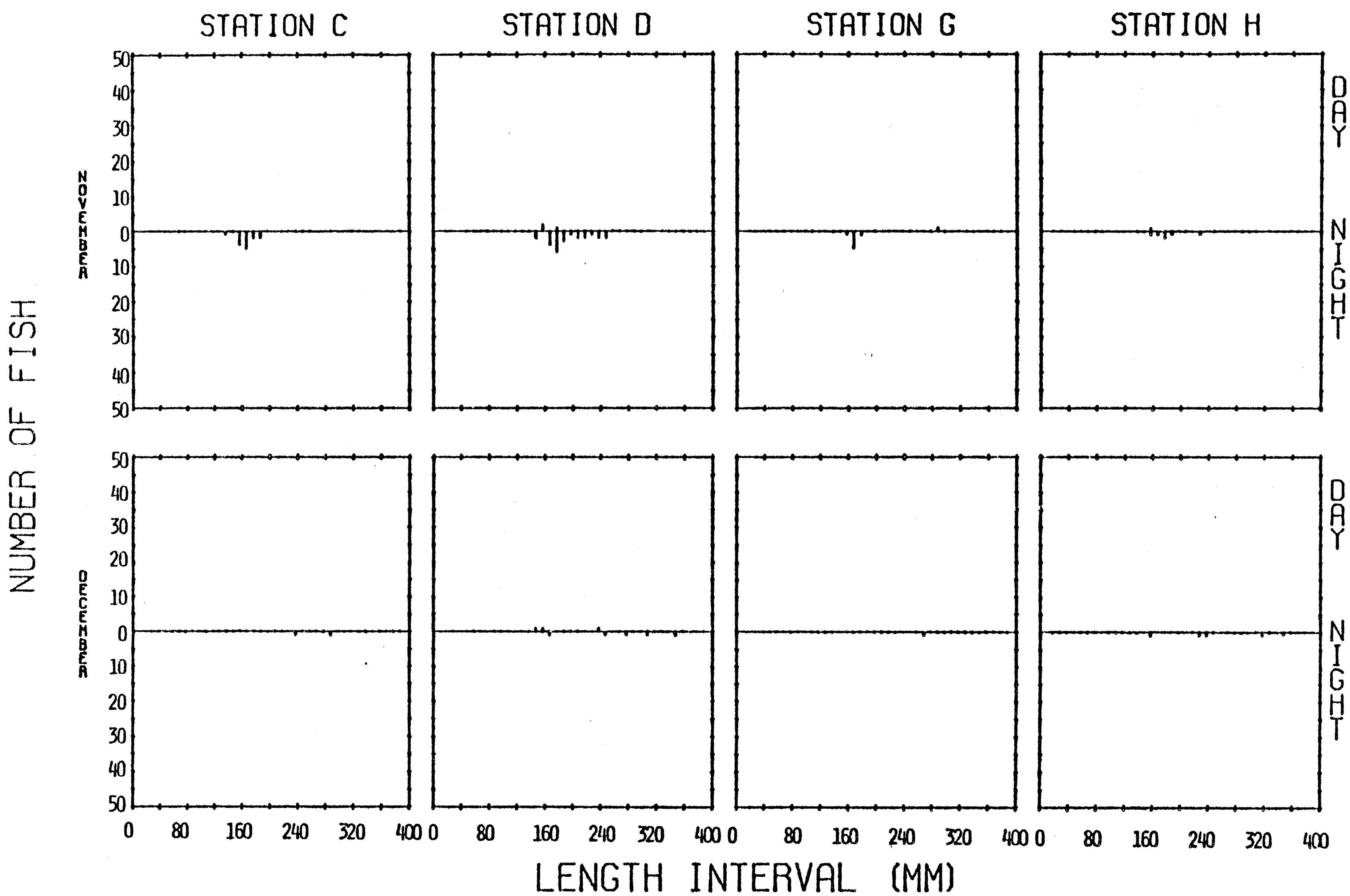

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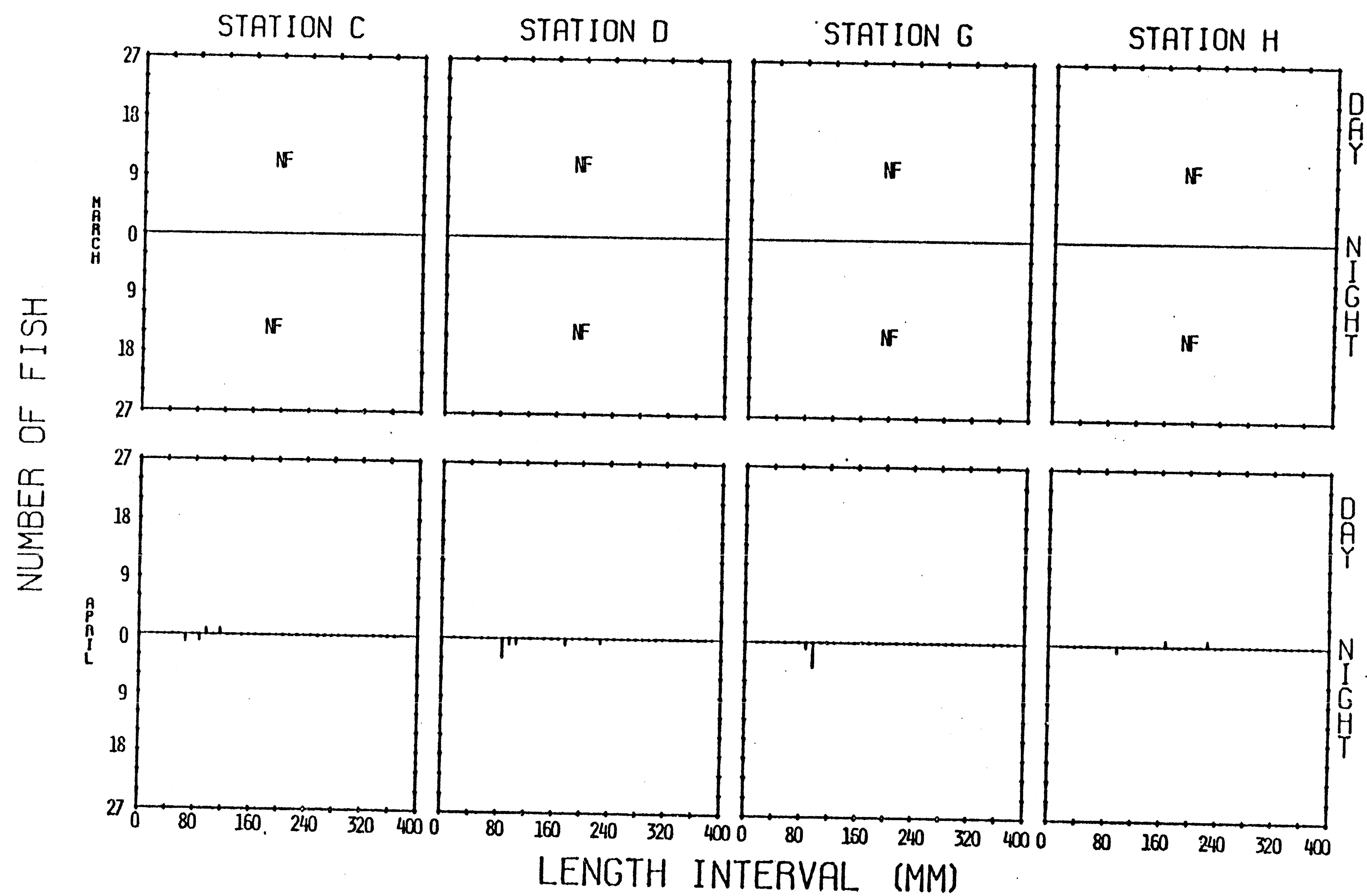
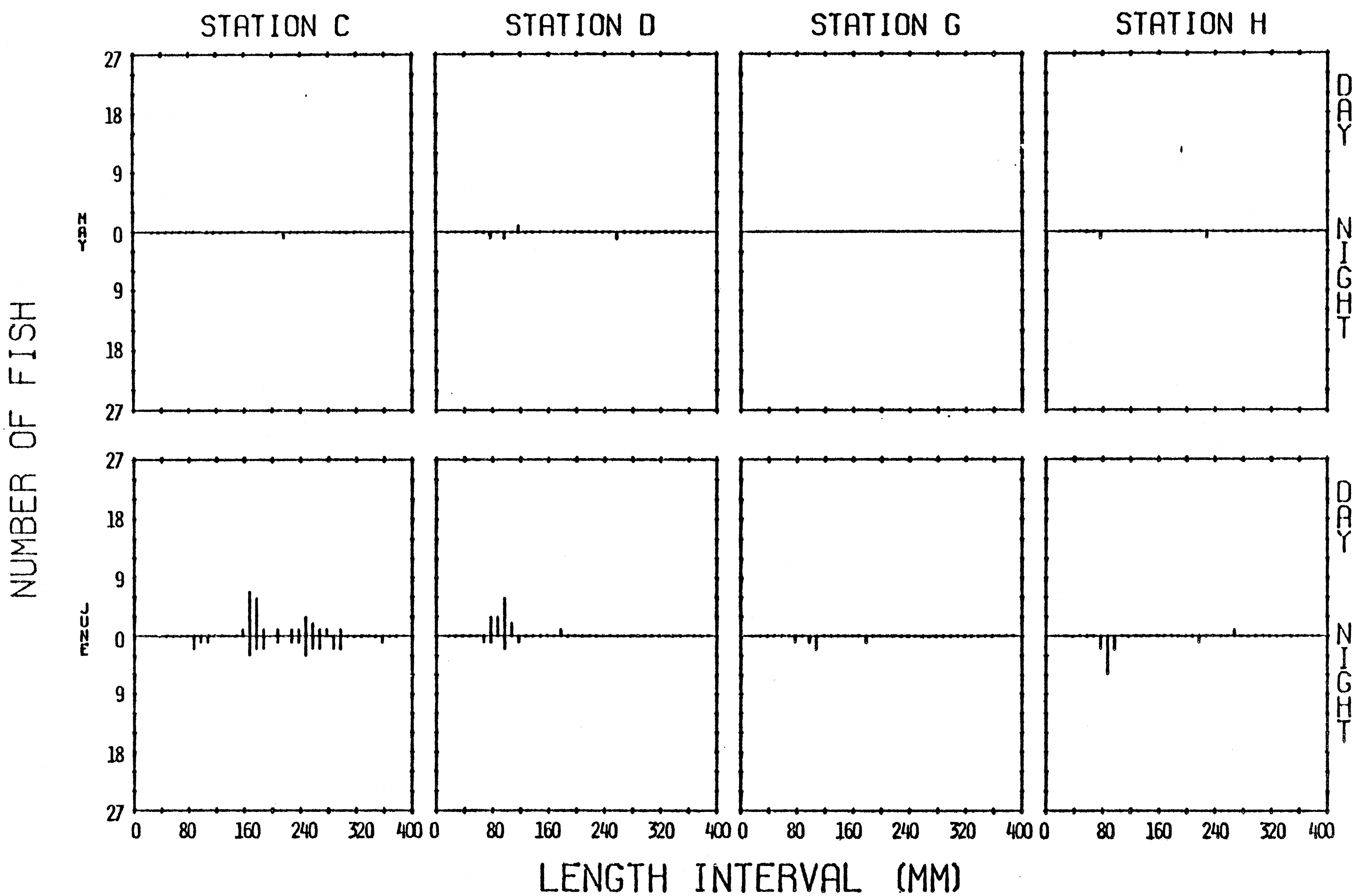


Fig. B54. Length-frequency histograms for yellow perch caught by standard series trawling during 1974 at Cook Plant study areas, southeastern Lake Michigan. NF = not fished.



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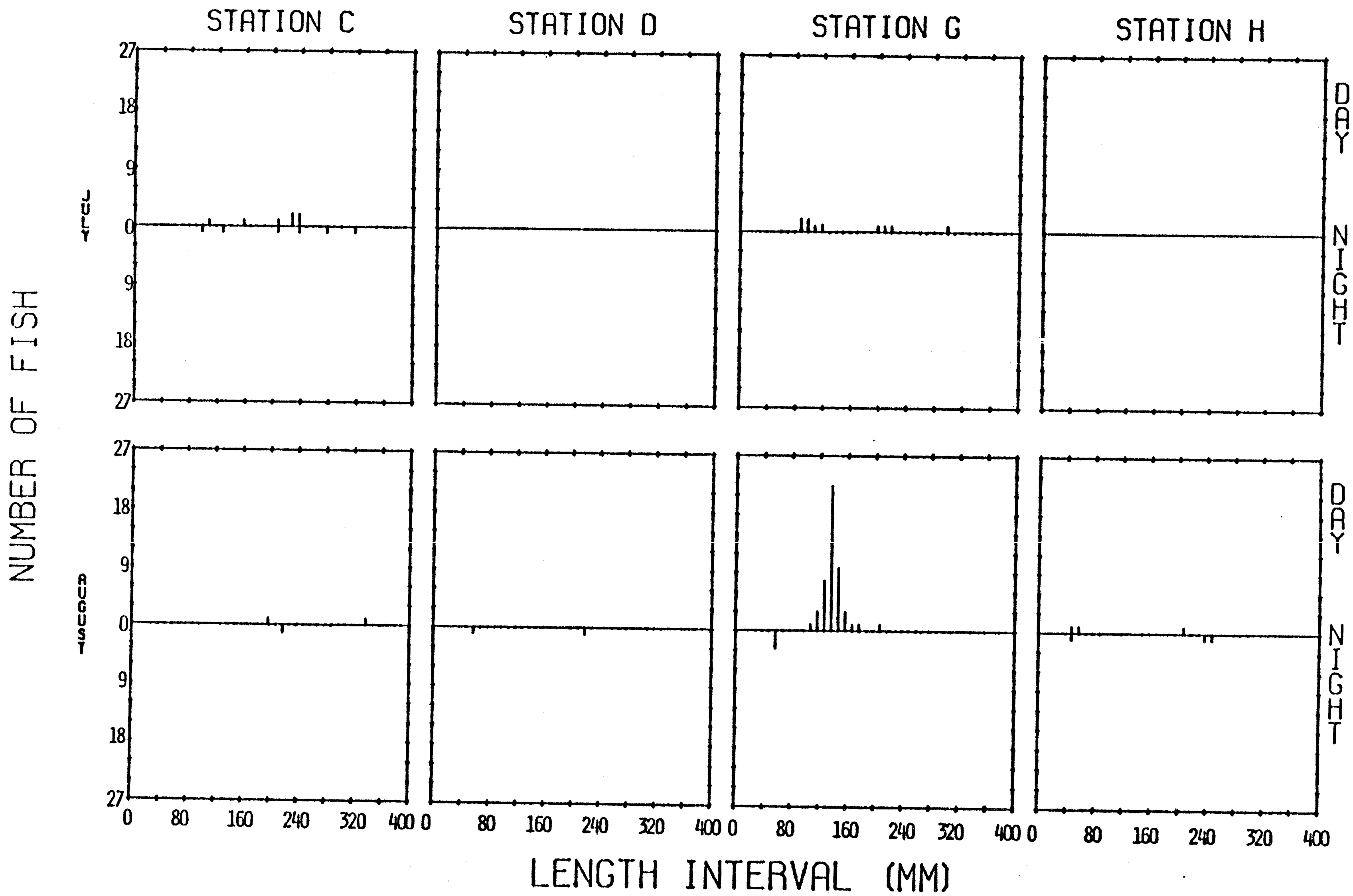

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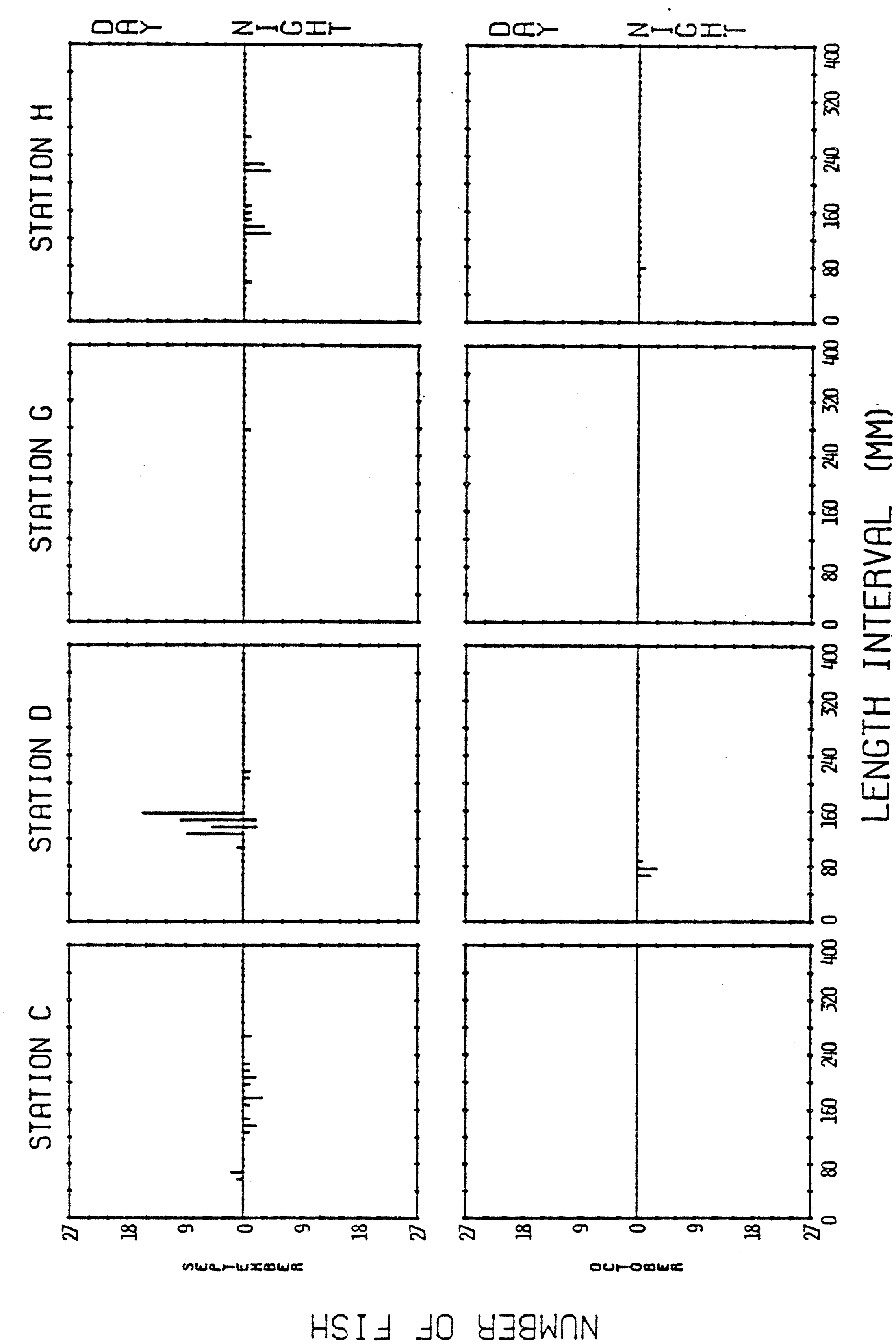

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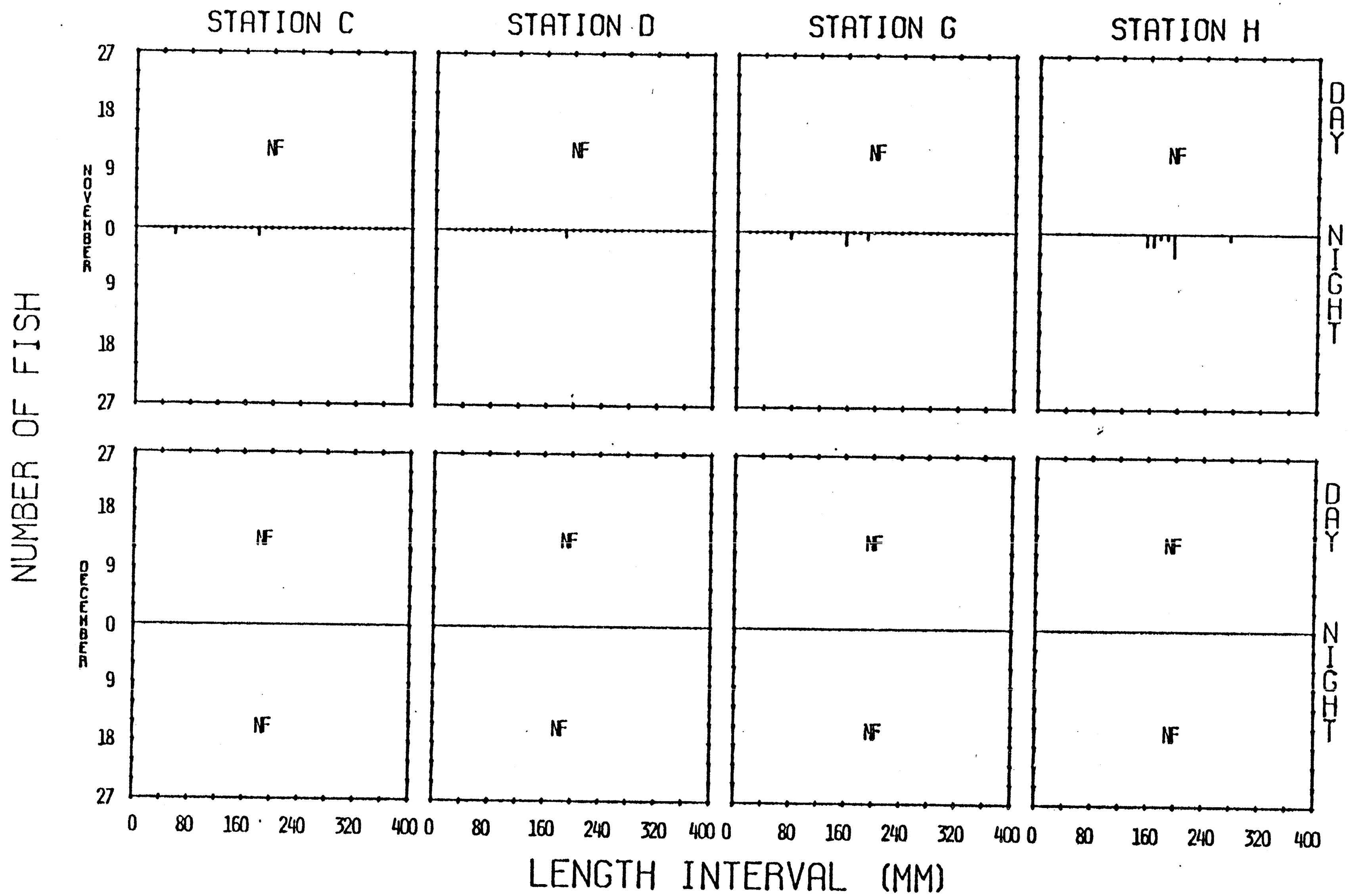


Fig. B54. Continued.

9 m, but inhabit shallower depths than the adult perch population.

Yearlings -- Yearling yellow perch of the 1973 year class were consistently impinged from January to June 1974 (see Fig. E1). Palisades data also showed yearling perch impinged consistently (although in low numbers) from January to mid-May 1973 (Consumers Power Company 1973b). As mentioned above (see Young-of-the-year --) the YOY population remained near 9 m from October to December, and as yearlings the population continued to remain near 9 m from January to June. Hergenrader and Hasler (1966) showed that during winter, yellow perch in Lake Mendota were concentrated in areas where depths were between 15-23 m, but schools of fish were diurnally active at depth intervals of 9-18 m. We suspect that in southeastern Lake Michigan during the winter and early spring the bulk of the yearling population is at depths somewhat greater than 9 m, but schools of perch enter the shallower depths to 6 m (and probably less) during the day. At this time they are susceptible to plant impingement. Undoubtedly low fishing effort from January through March prevented us from adequately describing yearling perch distribution from field catches alone. In April and May 1974 some yearlings (60-110 mm) were collected by trawls and gill nets at 6 and 9 m (Figs. B53 and B54).

Catch data of yearlings seined during June revealed that some fish were now inhabiting all inshore waters and in greater numbers than those caught earlier in the year (see Fig. B52). In July considerable numbers of yearlings (approximately 2400) were seined during the day and night, but few were trawled or gillnetted at 6 and 9 m. Evidently most of the yearling population was now in the shallowest areas of the inshore region. In August yearlings were still present in the shallowest areas (as revealed by large seine catches), but they also extended their range into deeper waters (gill net catches were large and trawl catches moderate in numbers). During September most yearlings left the beach zone for deeper water, but some were still present at 6 and 9 m. From October to December yearlings joined adults in migrating to water deeper than 9 m, although impingement data indicated that fringes of the yearling population were still near 9 m.

Adults -- While few adult yellow perch were collected in the study area during colder months (December, January, February and March) 1974, some were caught whenever gill nets were set (no nets were set in February). These data indicated that while the bulk of the adult population was in water deeper than 9 m during winter, some individuals moved into shallower water. This was probably an inshore schooling movement such as occurred with yearlings. Trawling data of Wells (1968) showed most adult perch in southeastern Lake Michigan during February were at 18 and 22 m. Allen (1935) found most Eurasian perch in Lake Windermere, England from November to March were at 18-27 m, although some were caught between 6 to 18 m. We set gill nets overnight at 21, 9 and 6 m on January 3, 1974 and caught 5, 0 and 1 adult perch at the respective depths, again suggesting most perch were at deeper depths. Probably the nocturnal inactivity of perch prevented the nets from adequately indicating depth distribution.

In 1974, moderate numbers of adults (large catches never occurred) were in the inshore area only during the warmest months, June through September. As mentioned above, low catches of perch in spring were a result of spawning outside the study area. The summer concentration was possibly due to inshore feeding activity. After September very few adults were caught because they left the area for deeper water. Very few (approximately 120) adult perch were caught by seining; most (90) were caught in July. Although there may be some seine avoidance by large adults, it still appears that adults rarely venture into the beach zone.

Comparisons of 1973 and 1974 distributions and growth by age-size class -- While the total standard series catch of yellow perch during 1973 was only 657 fish greater than the 1974 catch (see Tables B6 and B9), there were considerable differences in catches among age-groups (Table B37). Catches of all three age-groups showed dramatic changes between 1973 and 1974, with YOY (0 age-group) and adult (2 + age-group) catches declining sharply in 1974 and yearling (1 age-group) catches increasing (Table B37). All catches by gear type of each age-group declined in 1974 compared with 1973 except seine and gill net catches of yearlings. These age-group changes were attributed to more successful spawning in 1973 with therefore higher numbers of YOY present in 1973 and correspondingly more yearlings in 1974. We also suspect that summer temperature differences between years partially caused distribution changes in the perch population. Clearly these changes contributed to variation in catch analyses by gear type and added to the variation and interactions in statistical tests of the data (see Statistical analysis).

Table B37. Yellow perch of three age-groups collected during 1973 and 1974 from Cook Plant study areas, southeastern Lake Michigan.

	Gear type							
	Seine		Gill net		Trawl		Total	
Age-Group	1973	1974	1973	1974	1973	1974	1973	1974
0	50	41	21	0	433	20	508	61
1	459	3260	190	430	403	194	1052	3884
2 +	117	57	1379	433	825	99	2321	589

Young-of-the-year -- YOY perch grew to larger sizes in 1973 than in 1974 as a result of a faster growth rate in early and mid-summer. Perch

larvae collected by plankton nets in June of both years were approximately the same size (Fig. B55). By August, YOY in 1973 were 18 mm longer (difference in mean length) than 1974 YOY. Obviously, ecological conditions for growth were better during mid-June to early August in 1973. We concluded that two factors -- weather conditions (water temperature) and available food -- were responsible for better growth. Monthly average water temperatures during June, July and August were considerably warmer in 1973 than 1974 (see Fig. B6). Le Cren (1958), working with Eurasian perch from Lake Windermere, England, found that growth of perch at all ages was greater during years with warmer than average water temperatures. Ney and Smith (1975) found high temperatures in June, July and August appeared to exert a positive influence on growth of YOY yellow perch in Red Lakes, Minnesota. Although the above workers found strong growth - temperature relationships, Coble (1966) indicated that other studies have not found a similar pattern. He hypothesized that growth of fish is dependent on temperature, but other factors may mask the relationship.

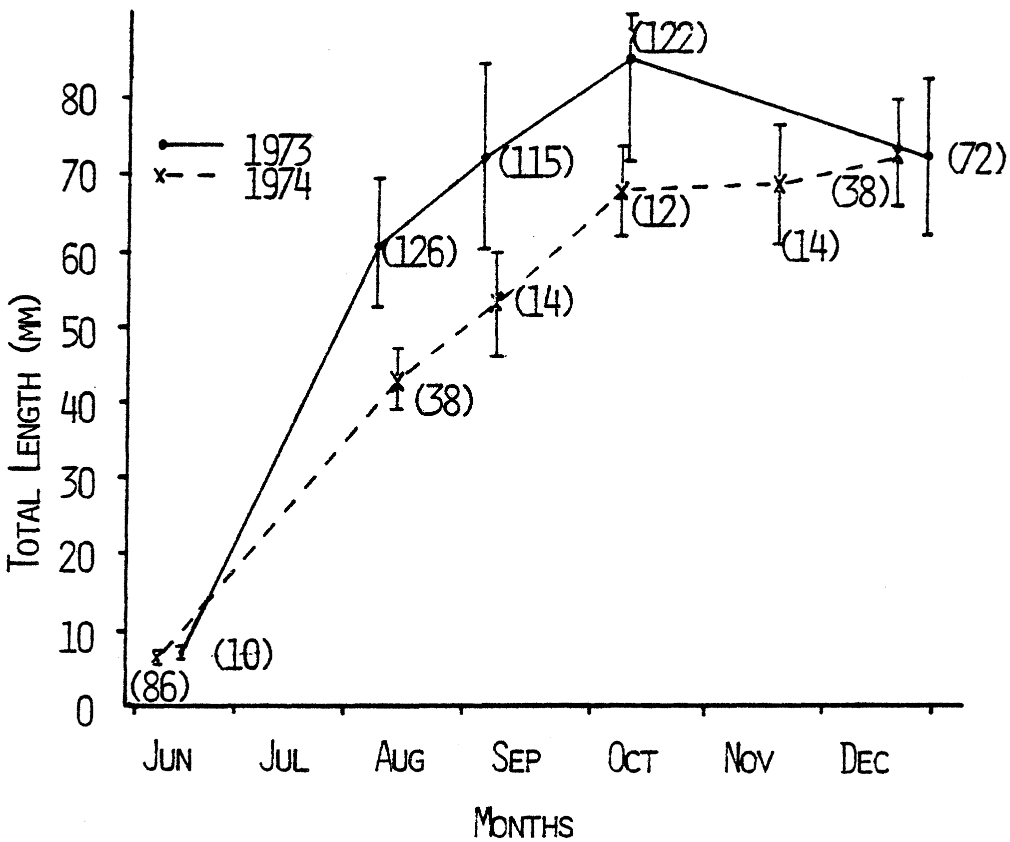


Fig. B55. Mean total length, standard deviation (bars) and number of yellow perch (parentheses) collected from Cook Plant study areas, southeastern Lake Michigan. Young-of-the-year yellow perch were collected by plankton nets in June, and by standard series sampling and impingement in August through December. Catches during July and November 1973 were not included due to low numbers of fish collected.

Available food may also have had an effect on growth of YOY at Cook Plant study areas. Other studies (Maloney and Johnson 1957, Pycha and Smith 1955 and Ney and Smith 1975) have shown that small (up to 30 mm) YOY feed predominantly on zooplankton (copepods and small cladocerans). Perch larvae also feed on small zooplankters (Siefert 1972). YOY, 30 mm and greater, feed more on larger zooplankters, benthic insect larvae and amphipods (Ney and Smith 1975). We also found YOY perch from 50 to 90 mm to feed on larger epibenthic zooplankters (especially Eurycercus), benthic insect larvae, amphipods and mysids (data not shown). Smaller YOY (50-60 mm) fed more on zooplankton, including small zooplankters. Therefore, YOY in our area would probably be feeding predominantly on small zooplankton during June to July and all sizes of zooplankton from July to August. Zooplankton data (M. S. Evans, personal communication, Great Lakes Research Division) showed higher concentrations of zooplankton present within the 10-m contour during June, July and August 1973 than in 1974. There was a 43% decrease (12,300 vs. 7000 / m^3) in total zooplankton during June 1974 compared to June 1973, a 38% decrease (27,000 vs. 16,700) in July 1974 and a 72% decrease (47,300 vs. 13,300) in August 1974. The decreased zooplankton population in 1974 may have contributed to poorer fish growth. Noble (1975) found variations in growth of fingerling yellow perch were directly attributable to annual variations in the density of Daphnia in Oneida Lake, New York. However, Nakashima and Leggett (1975) reported that at abundant food levels, yellow perch population size, and not growth, was enhanced in Lake Memphremagog, Quebec.

While temperature and available food apparently affected growth of YOY in the 2 yr, two other variables -- population density and YOY alewife competition -- evidently did not affect growth. In 1973 more YOY perch were present in the study areas than in 1974 (Figs. B56, B57 and Table B37). Evidently the greater density of yellow perch did not adversely affect their growth in 1973 compared to 1974 growth. Although only 2 yr have been compared, the data suggest that growth of YOY was not strongly density dependent in Lake Michigan study areas. Other investigators have found little evidence of a correlation between growth and population density of YOY perch (Pycha and Smith 1955, Le Cren 1958, Forney 1971, Noble 1975 and Ney and Smith 1975). The other factor which may influence YOY perch growth is food competition with YOY alewives. Small alewife larvae in Lake Michigan feed on small zooplankton and as the fishes grow they consume larger zooplankton (Norden 1968, Wagner 1975). Undoubtedly there will be competition between yellow perch and alewife larvae if both are present in the same area at the same time and food is limiting. Wagner (1975) concluded that larval alewife and larval perch were not competing for food in Little Bay de Noc, Lake Michigan because perch had outgrown the larval stage before alewives became abundant. In our area larvae of both species attained near maximum abundance during the third (1973) and second (1974) weeks of June (see Jude et al. 1975 and SECTION C). Since both species are pelagic, with perch strongly associated with the surface at early life stages ($\leq$ 8 mm), some food competition between these species must exist. Standard series catches during July to November revealed a 61% decline in YOY alewives during 1974 compared to 1973 (see. Fig. B23). Although more

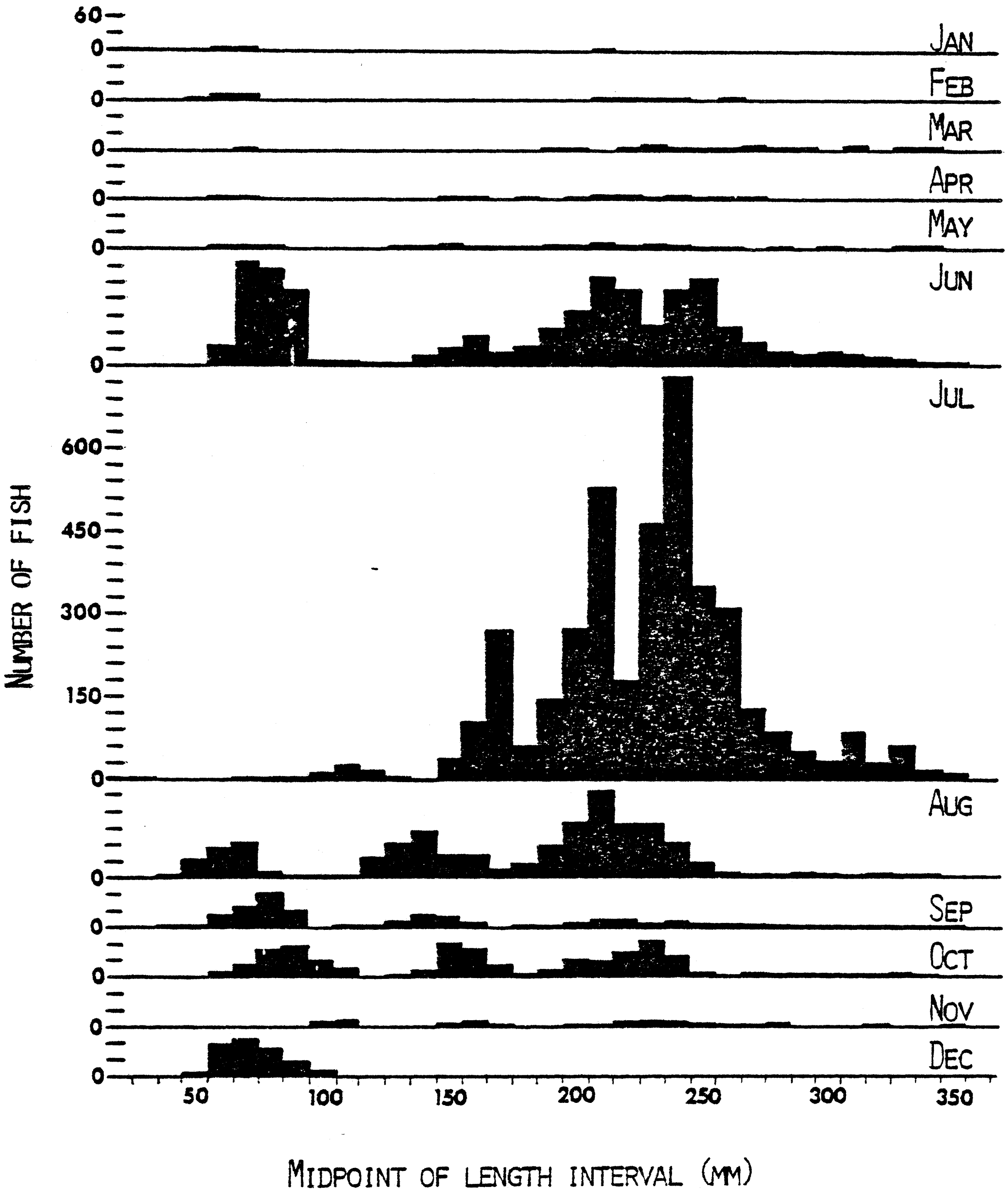


Fig. B56. Composite monthly length-frequency histogram of all yellow perch collected during 1973 at Cook Plant study areas, southeastern Lake Michigan.

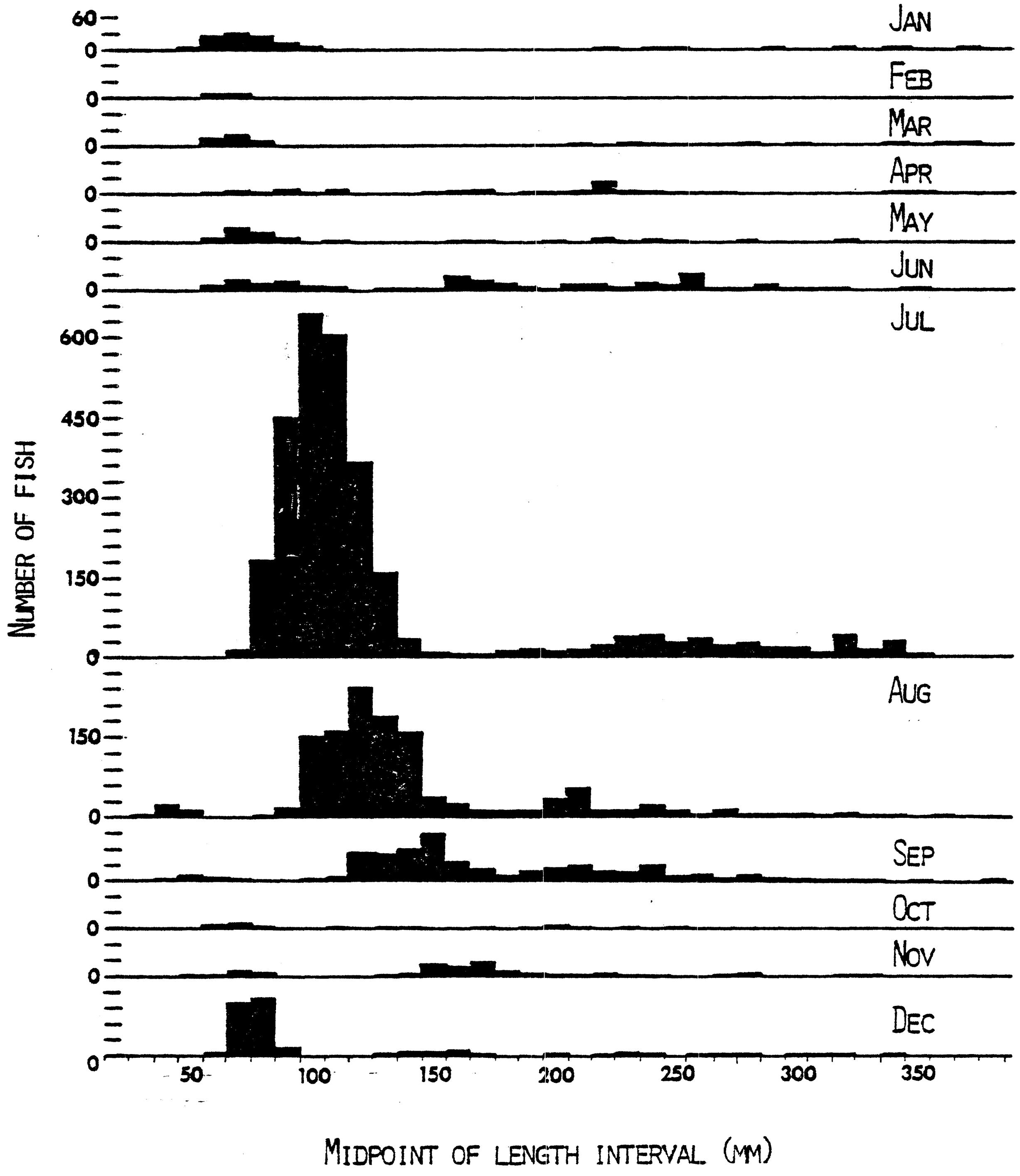


Fig. B57. Composite monthly length-frequency histograms of all yellow perch collected during 1974 at Cook Plant study areas, southeastern Lake Michigan.

YOY alewives were present in 1973 than 1974, growth of YOY perch was still better in 1973. Evidently during 1973 food was plentiful enough to not have been a significant element in early YOY growth. Probably food competition is an important factor during some years in the study area, but it was significantly overshadowed by the effects of water temperature during 1973 and 1974.

The above conclusions on effects of temperature, available food, population density and interspecific competition on early YOY perch growth are based on only 2 yr data. More data (additional years' growth measurements) will be needed for comparisons before we can accurately define these effects.

While growth of YOY perch was greater during early and mid-summer 1973, rate of growth from August to September and September to October was similar during both years (see Fig. B55). YOY growth during both years was completed during the beginning of October. Parkhurst (1971), Pycha and Smith (1955) and Ney and Smith (1975) also found YOY perch in western Lake Erie and in Red Lakes, Minnesota completed growth in October. Apparently the growing season is slightly longer in the Klamath River, California since Coots (1956) found YOY perch completed growth in October and November.

In 1973, mean length of YOY taken in December was somewhat lower than the October mean length (Fig. B55). This anomaly of a decline in length was probably the result of biased sampling. Only impinged fish were collected in December; therefore this sample was only taken at one depth and area. In December most larger perch are in waters deeper than 9 m and there may be some aggregations of YOY by size. Smaller YOY may also be more vulnerable to the plant intakes when they are in the area.

Summer growth rate of YOY in the Lake Michigan study area was about average compared to rates in other habitats (Table B38). The rate in 1973 (0.96 mm/day) was considerably above the average (0.7-0.8) while the 1974 rate (0.62) was somewhat below. An interesting aspect of the average values in Table B38 is that most are within a quite narrow range (0.71-0.87 mm/day). However Red Lakes data and ours indicate that considerable variation in growth can occur from year to year in the same habitat. Length at the end of first years' growth of perch also shows growth to be average in our study area. Data from various habitats reported in the literature revealed YOY perch averaged between 55-95 mm at the end of the year (see Table 2 in Coots 1956 and Table B27 in Jude et al. 1975). In the study area YOY perch averaged 86 mm in 1973 and 68 mm in 1974, at the end of the growing season. Growth of YOY perch in estuarine waters is apparently better than in fresh water habitats. Muncy (1962) reported yellow perch from the estuarine waters of the Severn River, a tributary of Chesapeake Bay, averaged (over 11 yr) 102 mm (males) and 114 mm (females) at the time of annulus formation.

Yearlings -- Considerably more yearling yellow perch were collected in 1974 than in 1973 (see Table B37). This change indicates that probably

Table B38. Summer growth rates of young-of-the-year yellow perch from various locations.

Location	Period	Growth rate mm/day	Authority
Red Lakes, Minnesota	Jul 8-Aug 14, 1952	0.35	Pycha and Smith 1955
	Jun 22-Aug 18, 1953	0.73	
	Jul 22-Aug 19, 1954	0.53	
Red Lakes, Minnesota	Jul 1-Aug 20 (Average of 12 yr 1952-1967)	0.72	Ney and Smith 1975
	Lowest (1952)	0.35	
	Highest (1963)	1.05	
Lake Winnibigoshish, Minnesota	Jun 23-Aug 19, 1954	0.71*	Maloney and Johnson 1957
Lake Mille Lacs, Minn.	Jul 1-Aug 20, 1954	0.75*	Maloney and Johnson 1957
Linwood Lake, Minnesota	Jun 12-Aug 28, 1954	0.51*	Lux 1960
Klamath River, Calif.	Jun-Aug 1951	0.87*	Coots 1956
Western Lake Erie	Jun 24-Sep 2, 1970	0.73*	Parkhurst 1971
Southeastern Lake Michigan	Jun 18-Aug 14, 1973	0.96	Present study
	Jun 11-Aug 9, 1974	0.62	

*Calculated from author's data

spawning success was better in 1973 than in 1972, although it is also possible that mortality was higher for the 1972 year class. These data coupled with YOY data strongly suggest that spawning success and YOY survival were very good in 1973 compared to 1972 and 1974. Again we suspect summer weather conditions in 1973 were favorable for perch survival in the study area. Average monthly temperatures for June, July and August 1972 were 5.4, 2.5 and 2.2 C lower than respective months in 1973. Clady (1976)

found survival of larval yellow perch was higher in years when mean water temperatures were higher in Oneida Lake, New York. He further reported that mean daily air temperature and mean daily wind velocity, during the egg to larvae stage of perch development, accounted for 87% of the variability in survival.

Length-frequency data indicate that very little change in length of yearlings occurred from January to May (see Figs. B56 and B57). Modal size of yearlings was consistently between 60-70 mm during January to May 1973 and 70-80 mm in the same period in 1974. Growth again resumed in June, as modal size increased during both years. In general changes in modal size indicated that growth of yearlings was about 20 mm per month from June to August and 10 mm per month from August to October. Growth was completed in October and November at which time modal size was 150-160 mm. This size after 2 yr growth was somewhat lower than Brazo et al. (1975) found for perch in central Lake Michigan. However compared to other areas, yearly growth in the study area was above average (see Table 3 in Brazo et al. 1975 and Table B27 in Jude et al. 1975).

While YOY perch grew better in 1973 than in 1974 yearling growth data also indicated that YOY in 1973 grew better than 1972 YOY. Size range of yearlings in 1973 (1972 year class) collected from January to May was 45-84 mm (modal size 60-70), however yearlings (1973 year class) collected during the same months in 1974 were 45-114 mm (modal size 70-80) (see Figs. B56 and B57). This size difference again suggests that growth and survival of YOY perch in 1973 exceeded that of the previous and following years.

Yearling growth was also better in 1973 than in 1974. While yearlings in early 1973 were smaller in size than yearlings in early 1974, by October to December they were both in the same size range 150-160 mm. Therefore, the increment in length made by yearlings in 1973 was more than that grown by yearlings in 1974. As discussed previously, apparently the higher summer temperatures during 1973 compared to 1974 allowed 1973 fish to grow much faster than their 1974 counterparts.

Adults -- As mentioned above, more adults were caught in 1973 than in 1974 (see Table B37). Standard series catches of adults from June to October, when compared to 1974, were greater for every month of 1973 except September. We believe the warmer temperatures in 1973 caused this increased abundance. From June to October 1973 average monthly water temperatures were from 1.5 to 3.2 C greater than those found in 1974, except for September (see Fig. B6).

In the above examinations of growth and abundance of YOY, yearlings and adults we have predominantly discussed the correlations with temperatures between 1973 and 1974. Further elaboration of this relationship is warranted here.

The interesting question is how did warmer water temperatures cause greater spawning success, greater YOY and yearling growth, and greater

abundance of adult perch in the study area during 1973? Warm water temperatures correlate with warm air temperatures and probably indicate fair-weather conditions. Warm air temperatures in the study area are caused by southerly winds which generally do not cause high waves. Cold air temperatures are the result of northerly winds usually causing high waves on the southeastern shore of Lake Michigan. High waves with resultant strong water movements on the bottom could interrupt adults spawning in shallow areas. Incubating eggs may be damaged or displaced by mechanical forces generated by strong waves and possibly damaged by abrupt temperature changes. Clady and Hutchinson (1975) noted that high wind-induced waves in Oneida Lake, New York dislodged considerable numbers of yellow perch eggs. Thus fair weather conditions would enhance chances for successful spawning and hatching of yellow perch in Lake Michigan. Warmer temperatures (within limits) would also physiologically give larvae a better chance at survival. Clady (1976) suggested that temperature and wind influenced perch year class size through a complex of many relatively minor mortality factors, rather than through one catastrophic event in Oneida Lake.

While relationships between temperature and fish growth are not always distinct (Coble 1966), it appears that growth is temperature-dependent (Weatherley 1972). Le Cren (1958) suggests that probably most of the effect of temperature is directly on the physiology of the fish. We suspect that this is also the case with YOY and yearling growth in the study area. Abundance and diversity of zooplankton and benthic invertebrates in the study area are probably great enough so that food is not limiting during most years. Predators eating faster-growing perch might be a factor biasing growth measurements, but we suspect that little predation occurs on perch (>25 mm). Preliminary examination of stomach analysis data show very few yellow perch in piscivorous fish stomachs (three burbot and one northern pike caught from 1973 through mid-1976 had perch in their stomachs). Probably there is predation on perch eggs and larvae, but we do not know the extent. These kind of components (other than temperature) are probably important factors affecting growth or early life stages during some years, but temperature was more important during 1973 and 1974 in the study areas. Growth data from future years may help to define these relationships.

Effects of temperature on adult perch abundance in the study area are not well understood. We can probably safely assume that overall warmer temperatures during the summer of 1973 caused or facilitated more adult perch to concentrate within inshore study areas. Mean monthly temperatures in June, July and August 1973 were 17.9, 18.8 and 19.7 C respectively. In 1974, mean temperatures were 14.9, 17.3 and 16.5 C. Other studies (Ferguson 1958, McCauley and Read 1973) showed that adult perch generally preferred temperatures between 18 and 21 C. Clearly, summer temperatures in 1973 were more favorable for perch than in 1974. Perch therefore concentrated inshore in 1973 because temperatures were in their thermal preference range. The interesting question now becomes where were the adult perch in 1974? Two suggested possibilities are that adult perch were in the general area during 1974 but they did not concentrate in the shallow study area depths, or that the fish moved to other warmer areas of southeastern Lake Michigan. It may

be that when inshore temperatures are not in the preferred range of yellow perch, the fish stay in water deeper than the study depths or the population is more spread out into shallow and intermediate depths. During summers when overall lake temperatures are low, warmer localized areas may exist near rivers (as the St. Joseph River) or farther south in Indiana and Illinois waters. Movement of perch to these areas might involve considerable distances, but this possibility exists. Studies on the movement of yellow perch in Green Bay, Wisconsin revealed most fish were recaptured within 32 km of the release point, but some (9 out of 108) fish moved 32-81 km (Mraz 1952). Whichever circumstance occurred in the study area remains unknown; and it is clear that we have much to learn about factors which affect yearly fish abundance in this part of Lake Michigan.

Temperature-catch relationships -- Yellow perch in the study area were most often (66% of the total standard series catch) caught between 18 and 24 C (Fig. B58). Largest catches (approximately 40% of the total) occurred at 21 C. Although laboratory experiments on fish temperature preference give variable results because of differences in acclimation temperature, season and size of fish, these studies show yellow perch preferred temperatures between 18.6-26.7 C (Ferguson 1958) and 17.6-23.3 C (McCauley and Read 1973). From summer field observations in lakes, Ferguson (1958) reported that yellow perch preferred temperatures between 19.7 and 21.2 C. Our field data agreed very closely with these ranges. Another interesting aspect of our field data is the very low numbers caught when temperatures were below 8 C (Fig. B58). This relationship is a result of most perch leaving the inshore waters of the study areas during colder months.

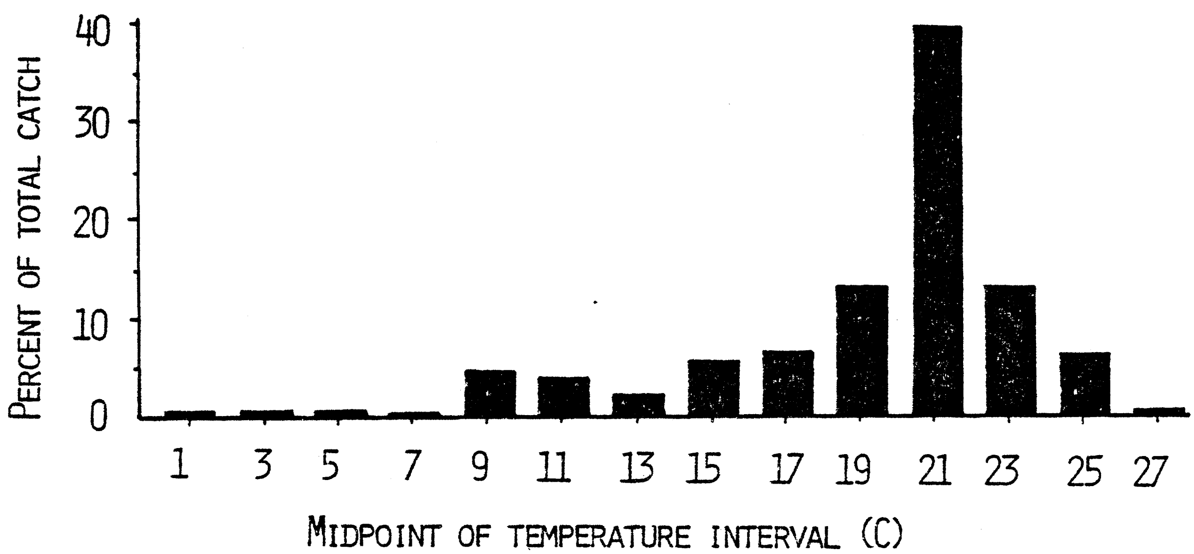


Fig. B58. Percentage of the combined total standard series catch of yellow perch for 1973 and 1974 collected from different temperatures at Cook Plant study areas, southeastern Lake Michigan.

Larger perch were generally caught in cooler temperatures than smaller fish (Fig. B59). Perch from 60-120 mm were most often caught in temperatures from 20 to 22 C, 130-220-mm perch from 16 to 19 C and 230-330-mm perch from 14 to 17 C. Mean temperatures for fish smaller than 60 mm and larger than 330 mm were quite variable because few fish were caught. Laboratory experiments of McCauley and Read (1973) and Barans and Tubb (1973) demonstrated that young perch selected temperatures higher than those preferred by adults (except in winter when adults selected warmer temperatures). Our temperature-catch data for alewives, spottail shiners, johnny darters and white suckers also indicated smaller fish were more often caught in warmer water than larger fish. Apparently age and size play a significant role in thermal selection by some fish species.

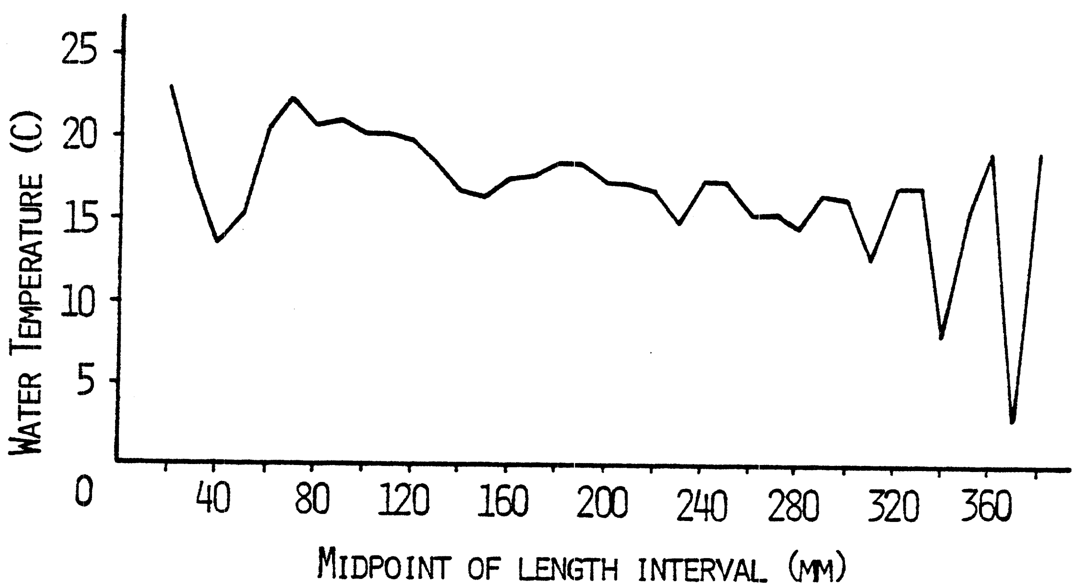


Fig. B59. Mean temperature at which different sizes of yellow perch were captured during 1973 and 1974 in standard series nets at Cook Plant study areas, southeastern Lake Michigan.

<u>Other considerations</u> -- Preliminary data on feeding by yellow perch revealed differences in behavior by season, sex and time of day (Table B39). Most feeding occurred in fall and summer with less occurring in spring and winter. Fall and summer feeding was probably related to post-spawning behavior and food availability. Brazo (1973) and Hauer (1975) found yellow perch in central Lake Michigan had the fewest empty stomachs in summer, slightly more in fall and most in spring. Very little feeding occurred over winter in the study area; fish that were feeding were caught in December. Although only 12 perch were caught and examined for food

Table B39. Percentages of yellow perch with food in the stomach that were collected in standard series nets at Cook Plant study areas, 1973-1974. N.D. = No data, M = male, F = female, I = immature, Spring = Mar-May, Summer = Jun-Aug, Fall = Sep-Nov, Winter = Dec-Feb.

		Spring	Summer	Fall	Winter
			1973		
Day	F	8	88	97	N.D.
	M	26	67	68	N.D.
	I	18	61	83	0
Night	F	18	47	90	0
	M	47	68	73	N.D.
	I	50	64	97	N.D.
			1974		
Day	F	N.D.	89	93	N.D.
	M	18	74	43	33
	I	43	50	40	17
Night	F	17	41	37	38
	M	50	73	63	20
	I	33	70	100	N.D.

	1973		1974	
	Day	Night	Day	Night
Female	81	59	89	37
Male	64	67	56	69
Immature	62	75	46	68

during January and February of both years, none had food in their stomachs. Scott and Crossman (1973) indicated that perch do actively take food in the winter.

Female perch had more empty stomachs during night, while immature fish had more empty ones during the day; males had slightly more empty stomachs during the day than night (Table B39). Keast and Welsh (1968) working on Lake Opinicon, Canada showed that 1- and 2-yr-old perch in June fed diurnally with two peaks in weight of stomach contents per gram of fish, one at sunset and another 4 h after sunrise. In Oneida Lake, New York, Tarby (1973) found that adult perch in summer began feeding at dawn and continued throughout the day; apparently some perch fed during the night. These data coupled with ours indicated that female perch in the study area fed more at sunset while immature fish fed more at sunrise. Apparently males were feeding during both periods.

Most (52%) larger perch, which were eating identifiable fish, consumed alewives (Table B40). Slimy sculpins and spottail shiners were also eaten in moderate numbers. Choices of fish eaten by yellow perch were probably related to abundance of prey species although slimy sculpins may be a preferred item as they are not nearly as abundant in the study area as are alewives, spottails, smelt and trout-perch (see Tables B6 and B9). Brazo (1973) and Hauer (1975) found larger yellow perch in central Lake Michigan consumed predominantly slimy sculpins, but ninespine sticklebacks, johnny darters, alewives, smelt and spottail shiners were also eaten. Brazo (1973) indicated that perch appeared to be opportunistic feeders rather than selective feeders. Our data also generally substantiate this conclusion.

Very few perch were consumed by piscivorous fish in the study area during 1973 and 1974. Of approximately 500 predatory fish examined which contained food (see Table B27) only one northern pike and one burbot were eating yellow perch. None of the salmonids (Table B27), yellow perch or smelt which were examined, ate yellow perch. This lack of predation may be due to the high abundance of other available prey species e.g., alewives, in the study area. Other fish species e.g., centrarchids, sauger and especially walleye which are known major predators of perch (Scott and Crossman 1973) are absent or uncommon in the study area.

Yellow perch in the study area are reaching maximum lengths reported for this species. Scott and Crossman (1973) give approximately 360 mm as maximum size, although one fish from Tucker Lake, Alberta was 381 mm in fork length. Longest perch collected by us during 1973 and 1974 was a 376-mm female weighing 738 g; heaviest perch was a 760-g female (365 mm). Brazo (1973) also found some perch in central Lake Michigan attaining large sizes; largest reported was approximately 390 mm and 780 g. Apparently large perch in Lake Michigan are not as heavy as record fish from other areas; Scott and Crossman (1973) gave a maximum weight of 1.9 kg. Brazo (1973) concluded that perch were reaching large sizes possibly as a result of the large alewife abundance in the late 1960's which reduced the perch population through larval food competition. The remaining perch then grew exceedingly

well. He further concluded that nutrients added to the ecosystem, because of the alewife die-off and decomposition, increased perch food organisms. We can add that lack of commercial fishing and fish predators in our study areas may also be important factors.

Table B40. Numbers of examined larger yellow perch eating various identifiable fish species. Perch were caught during 1973 through 1976 at Cook Plant study areas, southeastern Lake Michigan.

Species eaten	Number of yellow perch examined eating identifiable fish	Percent
Alewife	47	52
Slimy sculpin	19	21
Spottail shiner	10	11
Rainbow smelt	7	8.
Trout-perch	5	5.
Johnny darter	2	2
Golden shiner	1	1
Total	91	100

Trout-perch --

Trout-perch are native to and can still be found in all the Great Lakes. Although intermediate depths of the deeper lakes are typical habitats of trout-perch, they do move into shallower depths at night to feed and during the summer to spawn (Scott and Crossman 1973). There are no definitive studies on trout-perch in Lake Michigan, except for House and Wells (1973), who found the fish abundant in shallower waters of

southeastern Lake Michigan. We also found trout-perch moderately abundant seasonally in the shallow study areas of southeastern Lake Michigan during 1973 and 1974.

Statistical analysis --

Trawls -- In 1973 the trout-perch trawl ANOVA was performed on June-October samples only. A number of zero catches in April and May of that year forced exclusion of those months from the 1973 ANOVA for statistical reasons. During 1974 several zero catches occurred again in April and May. Consequently, the combined 1973-1974 ANOVA was computed for June-October data only.

Significant main effects ($p<.01$) of YEAR (Y), MONTH (M), DEPTH (D) and TIME (T) appeared in the 1973-1974 ANOVA (Table B41). AREA (A) was not significant, supporting speculation (Jude et al. 1975) that Cook and Warren Dunes stations provided similar environments in 1973 for this species. Although AREA entered into 1973 ANOVA interactions, it did not occur at all in the significant interactions of the combined 1973-1974 ANOVA, further confirming our inference of no difference between Cook and the Dunes.

There were five significant first-order interactions at $p<.01$: YxM, YxD, MxD, MxT, and DxT. Two significant second-order interactions also appeared, YxMxT and YxDxT, confounding main effects and first-order interactions (Table B41). We have attempted to explain the ANOVA by indicating biological and physical factors responsible for observed variances.

Significance of the main effect YEAR was caused by the decline in numbers of trout-perch trawled from 1973 to 1974. The significant interactions YxD and YxDxT were also affected by this decrease. In 1973, 3172 trout-perch were taken in standard series trawls, compared with 1315 in 1974, a 59% reduction. All age-groups (YOY, yearling, adult) appeared to be similarly affected (Fig. B60) unlike alewives, which experienced a comparable percent decrease (49%) mainly in the YOY class. From the graph of the YxM interaction (Fig. B61), it was evident that variation in trout-perch catch size between years was most pronounced in June and August. This time period coincides with trout-perch spawning season in Lake Michigan and suggests reduced spawning activity in 1974. Lower 1974 water temperatures in the study area (see Figs. B6 and B15) or yearly variation in alongshore distribution may explain the smaller 1974 trout-perch catch.

Seasonal distribution of trout-perch, both within and between years, was an important source of variance. The significance of the main effect MONTH was produced by annual movement of the species inshore in spring, followed by peak summer catches during spawning, then less extensive habitation of the study areas in fall (Fig. B61). More prolonged and more extensive habitation of the study area by trout-perch in 1973 than in 1974 accounted for most of the variance observed in the YxM interaction (Fig. B61) and probably contributed to the YxMxT interaction.

Table B41. Summary of analysis of variance for trout-perch caught in trawls at Cook Plant study areas from June through October 1973 and 1974.

Source of variation	df	Adjusted mean square[1]	F-statistic
YEAR	1	7.89996	76.04**
MONTH	4	1.66924	16.07**
AREA	1	.11135	1.07
DEPTH	1	1.26412	12.17**
TIME of day	1	14.16125	136.31**
YxM	4	1.66863	16.06**
YxA	1	.08189	.79
MxA	4	.32455	3.12
YxD	1	2.31034	22.24**
MxD	4	.87013	8.38**
AxD	1	.03833	.37
YxT	1	.22133	2.13
MxT	4	.43545	4.19*
AxT	1	.05590	.54
DxT	1	3.88976	37.44**
YxMxA	4	.20813	2.00
YxMxD	4	.27645	2.66
YxAxD	1	.13549	1.30
MxAxD	4	.20133	1.94
YxMxT	4	1.45185	13.98**
YxAxT	1	.26762	2.58
MxAxT	4	.24369	2.35
YxDxT	1	.84119	8.10*
MxDxT	4	.11494	1.11
AxDxT	1	.17461	1.68
YxMxAxD	4	.31769	3.06
YxMxAxT	4	.32355	3.11
YxMxDxT	4	.08212	.79
YxAxDxT	1	.02152	.21
MxAxDxT	4	.35639	3.43
YxMxAxDxT	4	.11912	1.15
Within cell error	79[2]	.10389	

** Significant ($P < .001$).
 * Significant ($P < .01$).

1 Mean squares were multiplied by harmonic cell size/maximum cell size ($n_h/N = .9877$) to correct for 1 missing observation where the cell mean was substituted.

2 One degree of freedom was subtracted to correct for 1 missing observation where the cell mean was substituted.

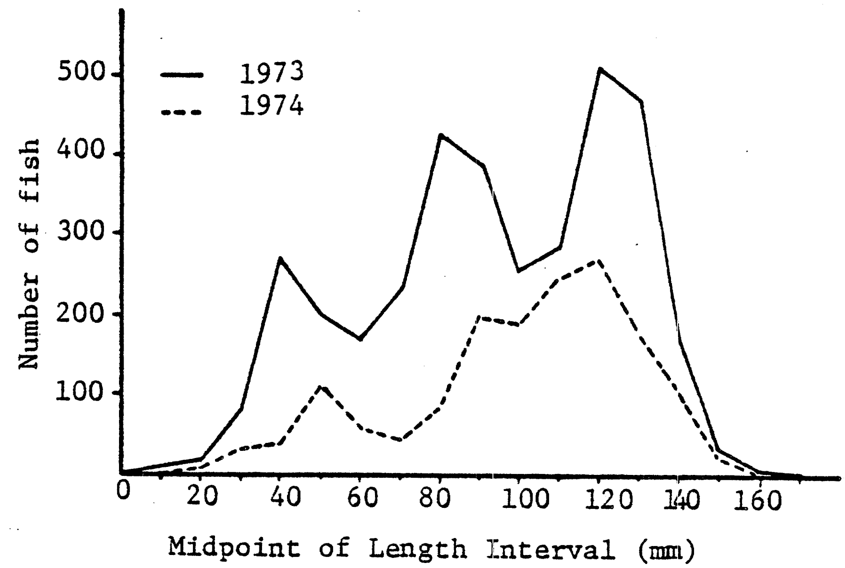


Fig. B60. Comparison of 1973 and 1974 total standard series catches of trout-perch by length interval in Cook Plant study areas, southeastern Lake Michigan.

Other major sources of variance in the trawl data were the large July 1974 day catch of trout-perch at 6 m (Fig. B62) and the large night catch of June 1973. Generally trout-perch were more abundant in our night trawl catches, since this fish characteristically moves shoreward at night (Magnuson and Smith 1963, Scott and Crossman 1973, McPhail and Lindsey 1970). In fact, overall predominance of night-caught trout-perch during 1973 and 1974 produced the significant main effect TIME. Thus, the June 1973 night catch, while sizable, was not entirely unexpected. The greater numbers of trout-perch observed during that month were probably a reflection of spawning activity in the study area. The large daytime catch in July 1974 was more unusual biologically since we typically caught fewer trout-perch in day trawls, thus the large catch may have resulted from spawning or an upwelling, or both. This event has been discussed in great detail below under <u>Seasonal distribution by age-size class</u>. Both the June 1973 and July 1974 trawl catches probably contributed to the significance of the MxD, YxM and YxMxT interactions.

Graphs of some of the ANOVA interactions, without knowledge of the unusual nature of the July 1974 catch, could result in misleading conclusions about trout-perch biology. The graph of the MxD interaction superficially suggests trout-perch moved to shallower water from June to July (Fig. B61). Actually, large 1973 night catches in June at 9 m and the peak July 1974 daytime catch at 6 m accounted for this pattern, not

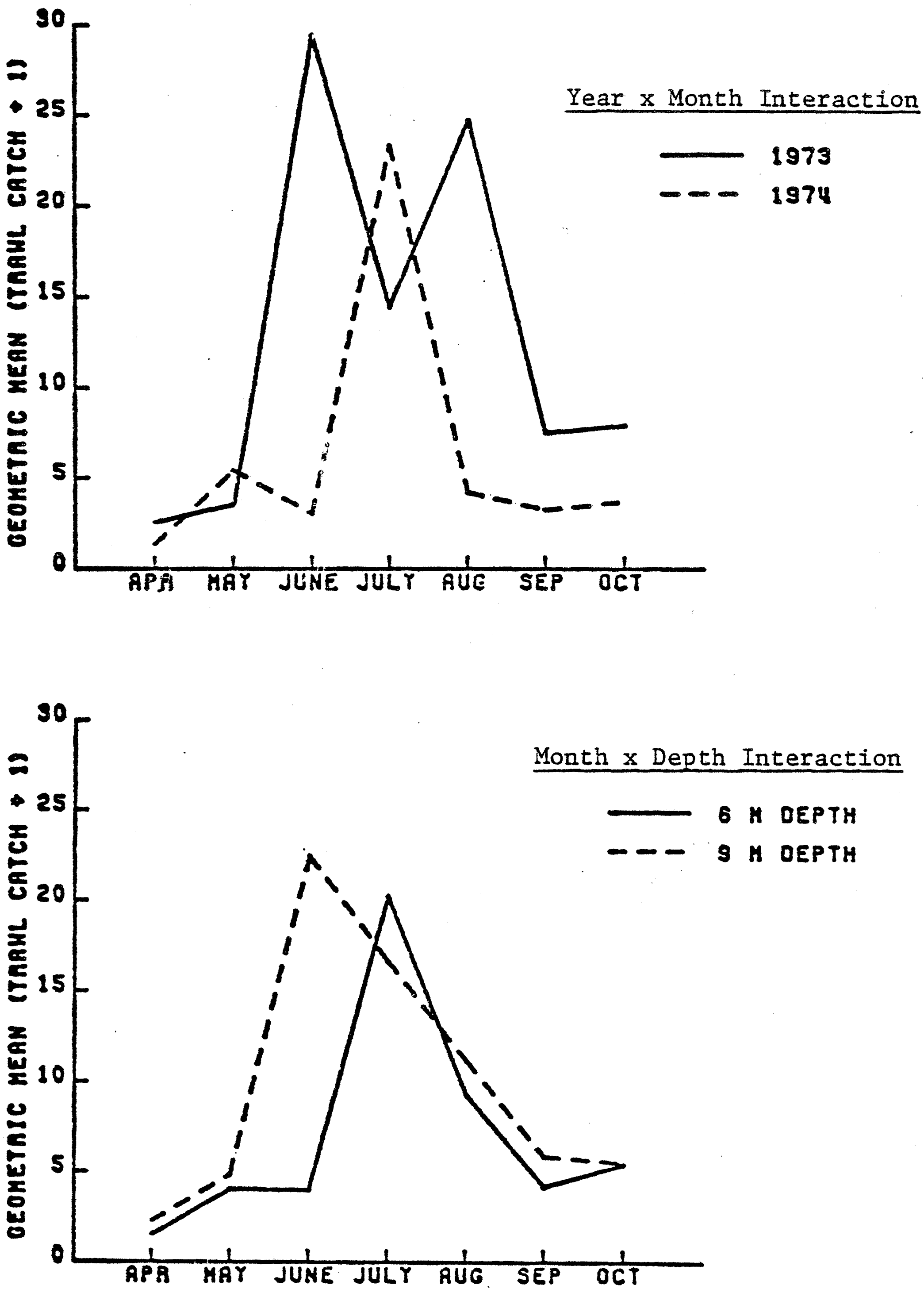


Fig. B61. Geometric mean number of trout-perch caught in standard series trawls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

shoreward movement of trout-perch from June to July. Inspection of monthly length-frequency histograms for 1973 and 1974 (Fig. B63 and Jude et al. 1975, Fig. B40) confirmed this, showing that the entirety of the data must be examined in order to understand how a species is distributed in the study area.

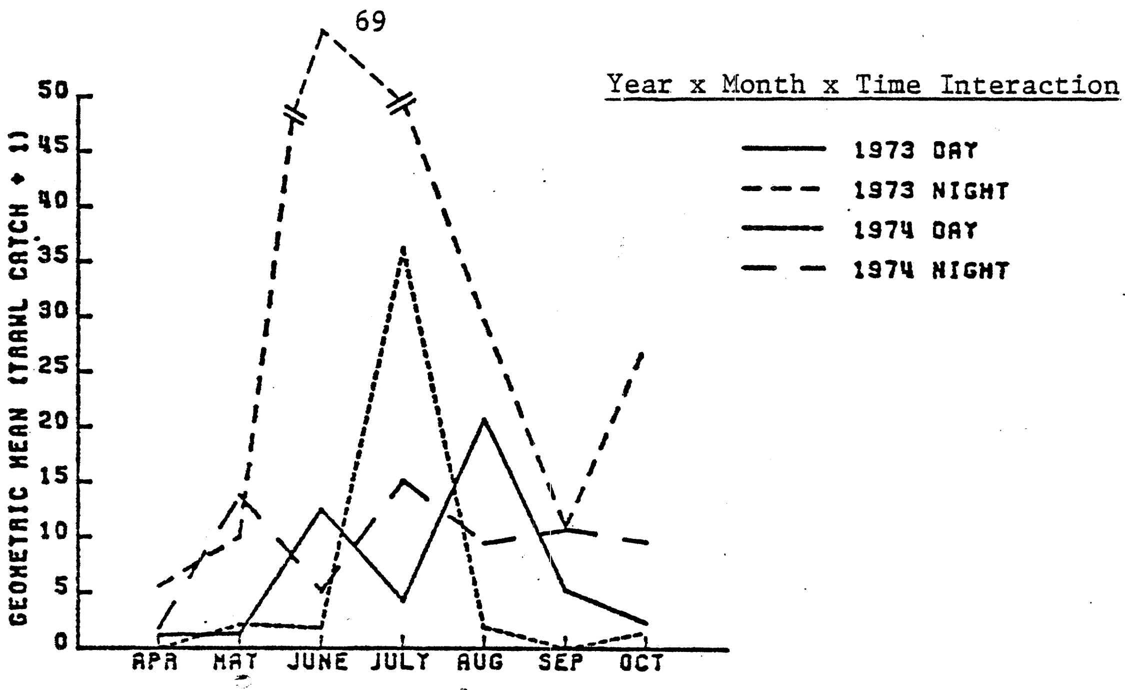


Fig. B62. Geometric mean number of trout-perch caught in standard series trawls during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

The main effect of DEPTH (more trout-perch trawled at 9 m than at 6 m) and the interaction DxT, while statistically significant, were difficult to explain biologically and were probably the product of sporadic large catches of trout-perch at a particular depth and time in the study area. The interactions YxD and YxDxT were also affected. Uneven distribution of trout-perch with respect to depth, perhaps associated with schooling behavior, was thought to be the cause of these unpredictable catches. From June to October 1973, 9-m day trawl catches were routinely greater than 6-m day trawl catches, except in October (Fig. B40 in Jude et al. 1975), as might be expected in daytime when the species is further offshore. However, 1974 data did not confirm concentration of trout-perch at either depth contour (6 or 9 m) during day or night (Fig. B63). It was evident that the 6-m and 9-m catch differences were not always sufficient to demonstrate the diel inshore-offshore movement indicated by generally greater abundance of

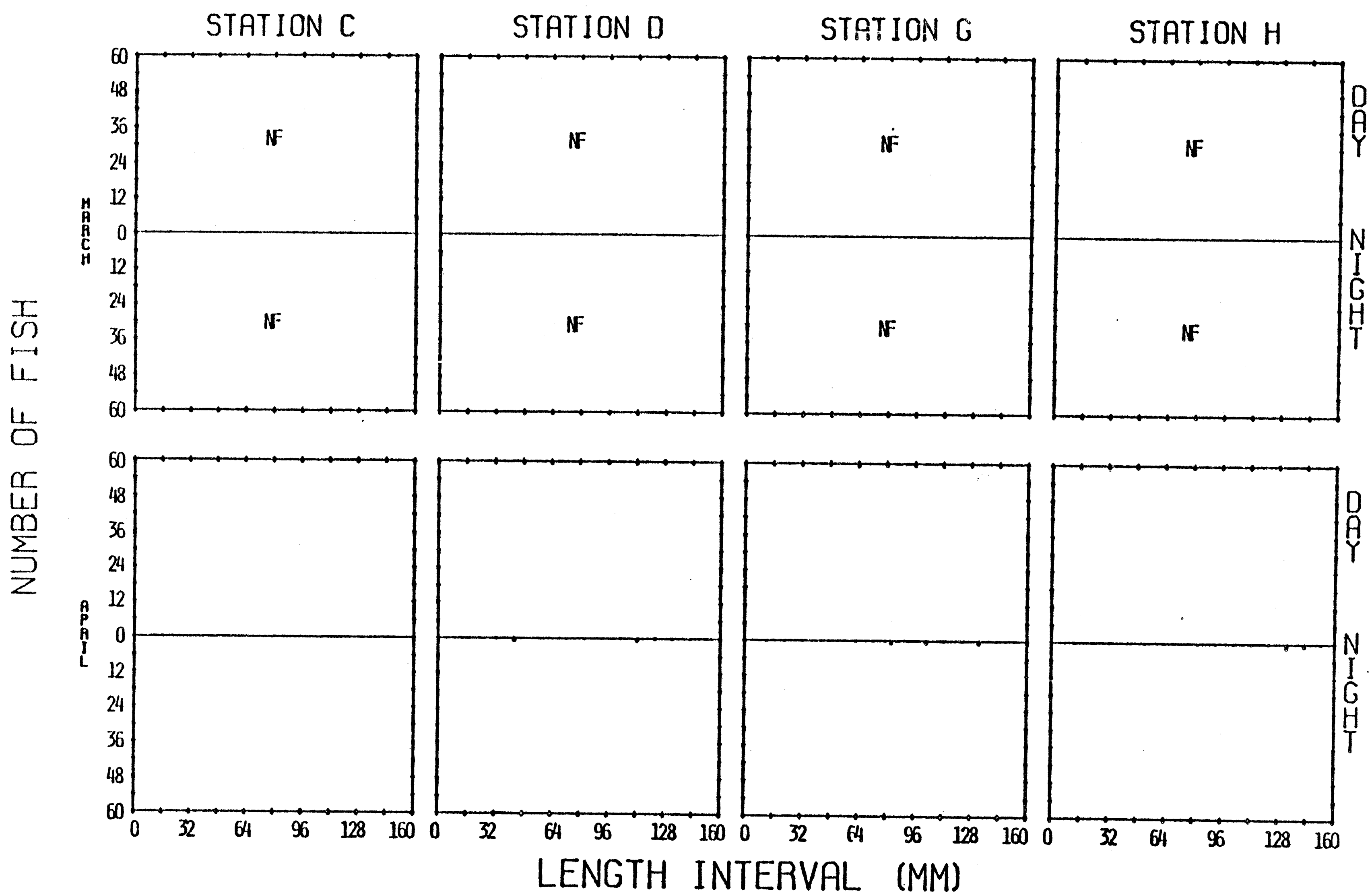


Fig. B63. Length-frequency histograms for trout-perch caught by standard series trawling during 1974 at Cook Plant study areas, southeastern Lake Michigan. NF = not fished.

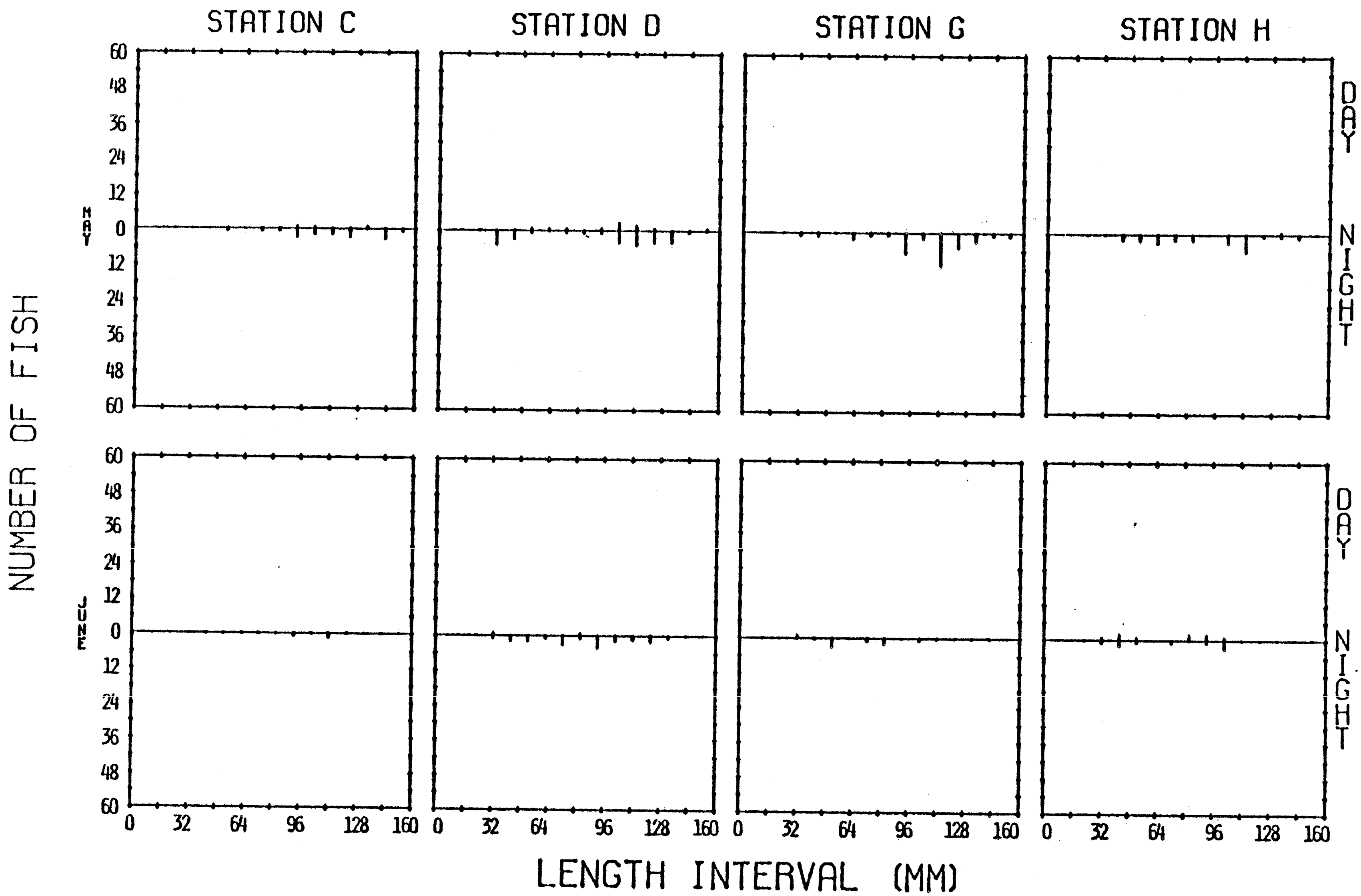
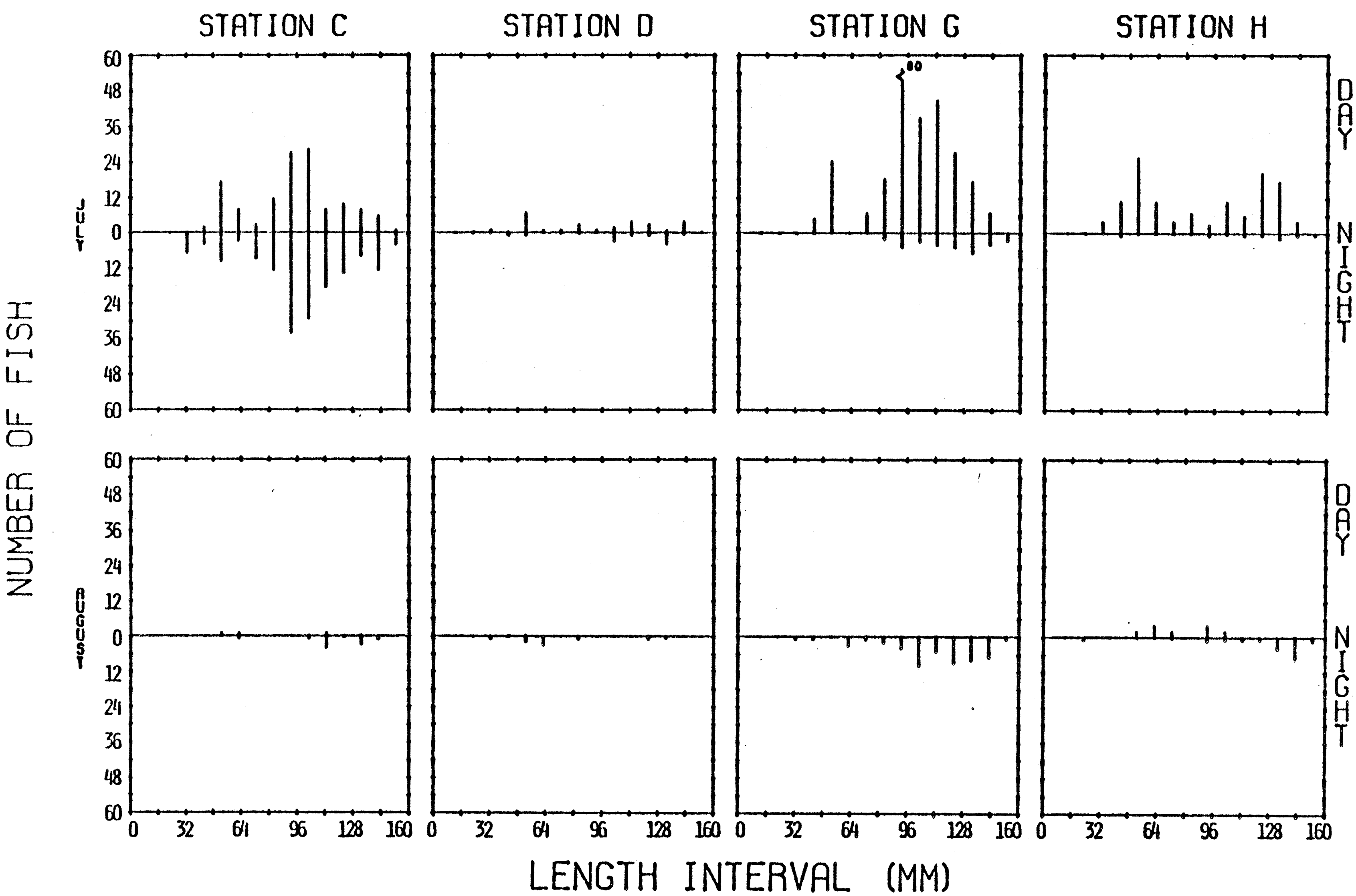


Fig. B63. Continued.



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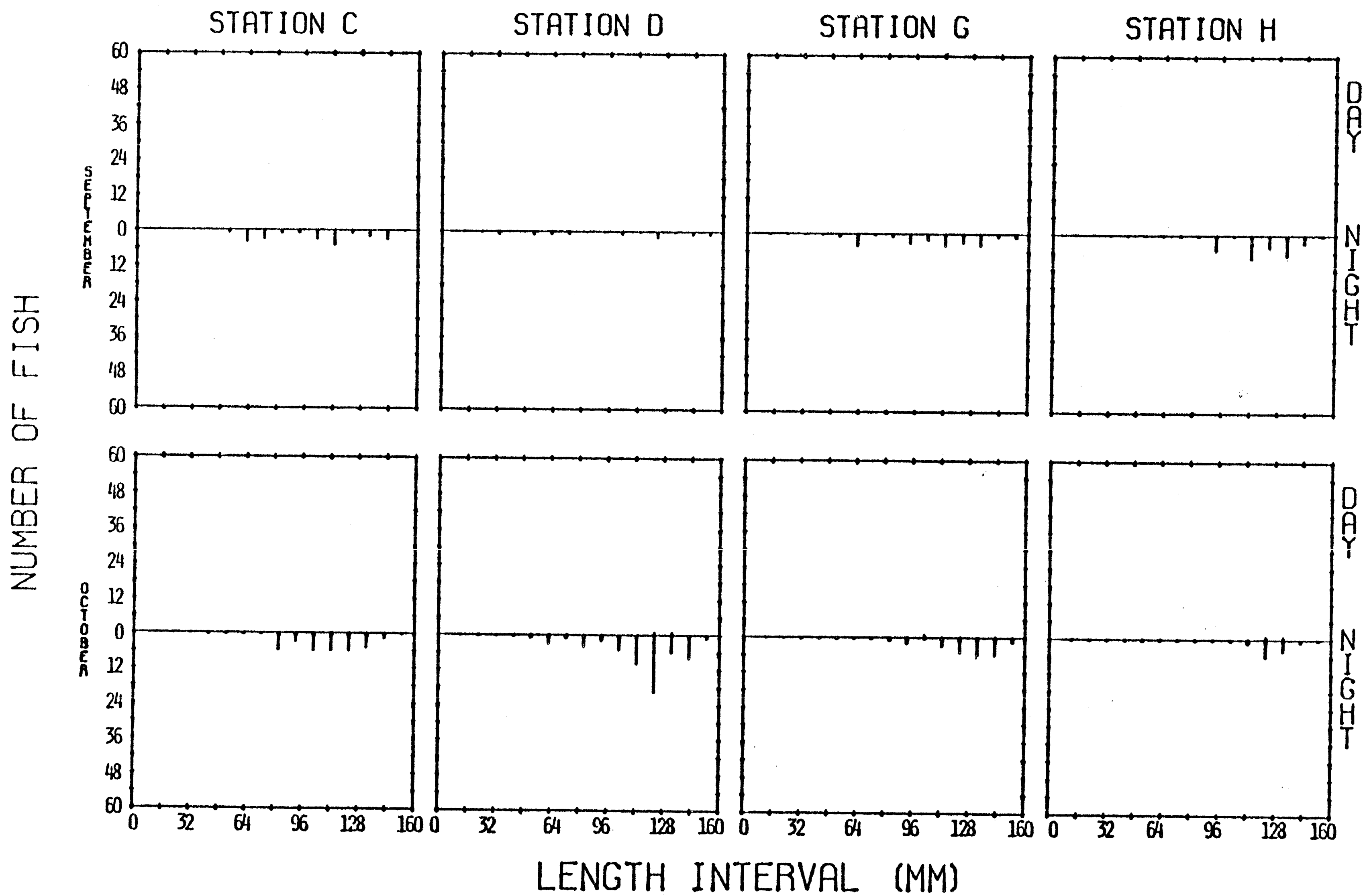

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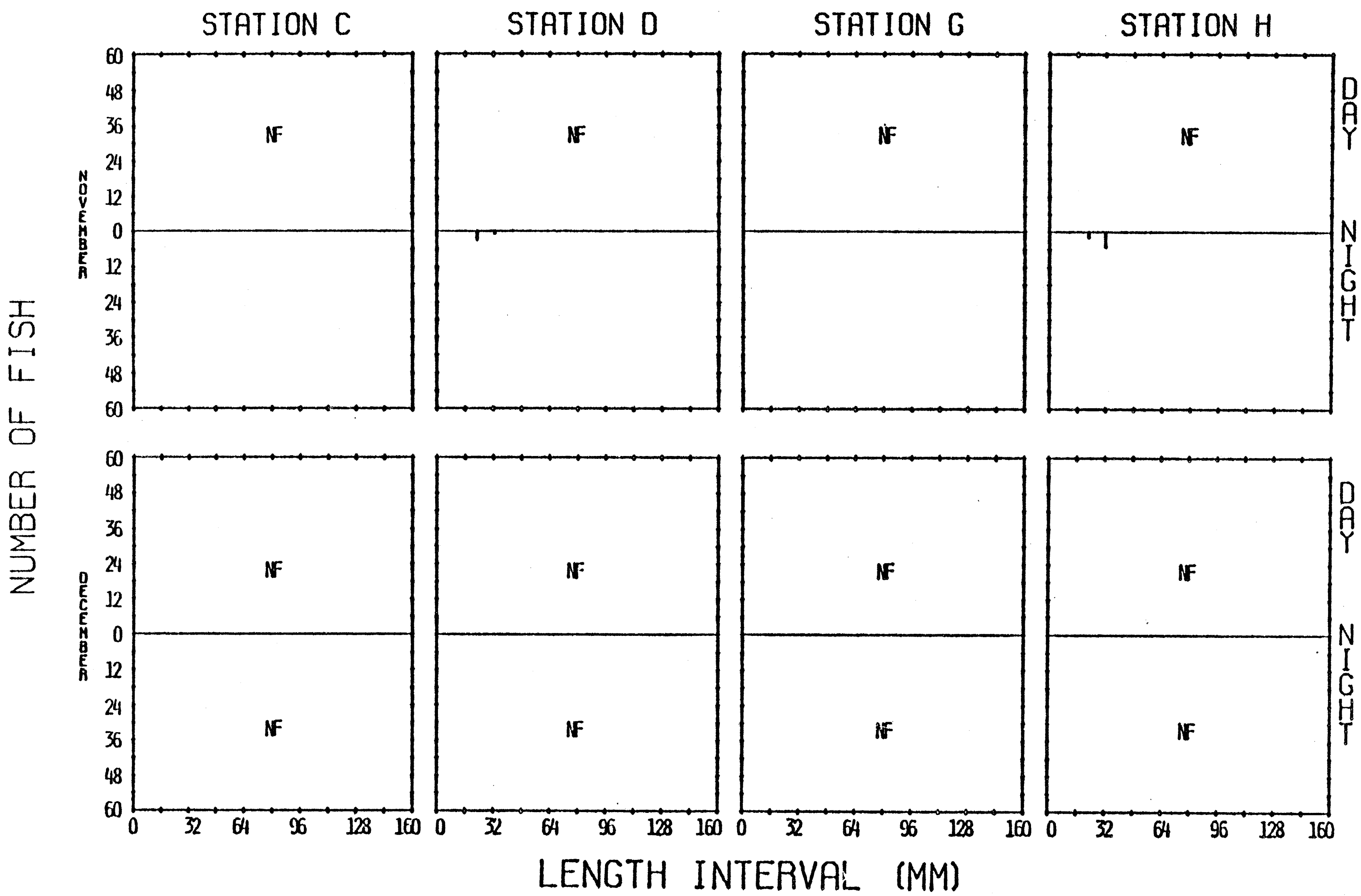


Fig. B63. Continued.

trout-perch in night trawls.

Gill nets -- Acquisition of 2 yr of gill net data enabled us to employ the Wilcoxon and Median (Sign) tests in our evaluation of 1973-1974 gill net catches, using monthly paired comparisons of data between years (see SECTION A). The only significant effects in the Wilcoxon and Median (Sign) tests for 1973 and 1974 trout-perch gill net data were TIME and AREA (Table B42). In the Wilcoxon test night catches were significantly larger than day catches in all but two cases: 1973, Cook 9-m station (no difference) and 1974, Cook 6-m station (no decision). The Median (Sign) test gave similar results for TIME effects (Table B42), except that it indicated no difference between day and night catches for the Warren Dunes 9-m station in 1974. Even when night catches were not statistically greater than day catches they usually exceeded day catches numerically, on a monthly basis. Thus, gill net data reflected the typical nocturnal inshore migration of this species. Gill nets were set on the lake bottom and were well situated to detect such benthic diel movements.

AREA was significant only in the Wilcoxon test, where 1973 9-m night catches at Warren Dunes were greater than those at Cook (Table B42). This pattern did not appear at 6-m stations, nor was it repeated in 1974. Uneven distribution of trout-perch in the study area was thought to be responsible for this effect, rather than actual preference for Warren Dunes. The Mann-Whitney and Kruskal-Wallis tests, applied to 1973 data (Jude et al. 1975), did not show any significant AREA effects, probably because these two tests examined the year as a whole rather than pairing data by month, as was done in this report. Diel differences in gill net catch were not examined statistically in the 1973 report (Jude et al. 1975).

The Wilcoxon and Median (Sign) tests were unable to assess seasonal patterns in gill net data, so these must be reviewed non-statistically. The 1973 seasonal trends have already been discussed in Jude et al. 1975; 1974 gill net catches paralleled those of 1973 (Fig. B64). In 1974 gillnetted trout-perch accounted for 15% (242 fish) of the total standard series trout-perch catch. By comparison 7% (260 fish) of the 1973 trout-perch catch were gillnetted. In both years there were many zero catches of this species in gill nets. Lower abundance of trout-perch in the study area compared to the other four most abundant species, small size and a smooth body surface are responsible for scarcity of this fish in gill nets.

Gill net catches of trout-perch followed seasonal changes exhibited by trout-perch catches from other gear types. In 1974 peak gill net catches of trout-perch occurred in May (spring inshore movement), July (during spawning season) and October (Fig. B64). At Cook and Warren Dunes 9-m stations the summer maximum gill net catches extended into August (Fig. B65), a trend not seen in the much larger August 1974 trawl catches. October gill net data suggested, as did data from trawls and seines, that trout-perch do not leave the study areas entirely during fall and may even concentrate there for a short period in autumn. No reference to extensive fall habitation of the inshore zone (shoreward of the 9-m contour) by trout-perch occurs in the

Table B42. Results of Wilcoxon and Median (Sign) tests of paired comparisons of standard series gill net catches of trout-perch in Cook Plant study areas, southeastern Lake Michigan during 1973 and 1974. Factors were Year, Area, Depth and Time with comparisons in the table given in the same order. Tests were conducted at α = .10. NS = Nonsignificant; NT = No test, insufficient non-zero differences.

TEST	TEST RESULTS							
YEAR	Cook Plant				Warren Dunes			
	6M		9M		6M		9M	
	day	night	day	night	day	night	day	night
Wilcoxon	NT	NS	NT	NS	NT	NS	NS	NS
Median	NT	NS	NT	NS	NT	NS	NS	NS
AREA	1973				1974			
	6M		9M		6M		9M	
	day	night	day	night	day	night	day	night
Wilcoxon	NT	NS	NS	Dunes>Cook	NT	NS	NT	NS
Median	NT	NS	NS	NS	NT	NS	NT	NS
DEPTH	1973				1974			
	Cook Plant		Warren Dunes		Cook Plant		Warren Dunes	
	day	night	day	night	day	night	day	night
Wilcoxon	NT	NS	NT	NS	NT	NS	NT	NS
Median	NT	NS	NT	NS	NT	NS	NT	NS
TIME	1973				1974			
	Cook Plant		Warren Dunes		Cook Plant		Warren Dunes	
	6M	9M	6M	9M	6M	9M	6M	9M
Wilcoxon	night>day	NS	night>day	night>day	NT	night>day	night>day	night>day
Meidan	night>day	NS	night>day	night>day	NT	night>day	night>day	NS

literature. It is suspected that this pattern represents a reaction of trout-perch to the cooling of offshore waters in fall, causing them to return temporarily to warmer nearshore water. Similar autumn catch increases have been observed from time to time for other species in the study area. These patterns of autumnal abundance should be considered when evaluating seasonal abundance of fish in the study areas between preoperational and operational years.

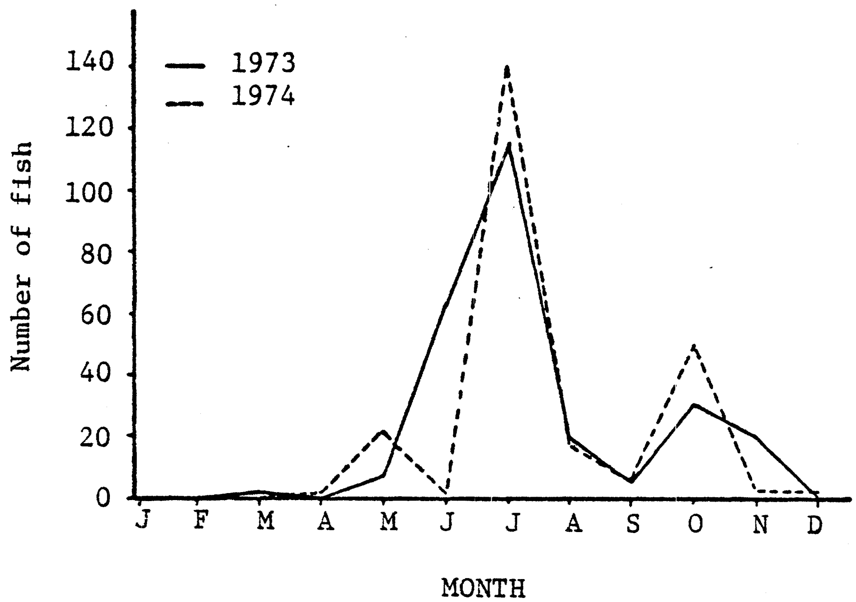


Fig. B64. Total number of trout-perch caught in standard gill nets by month and year (1973-1974) in Cook Plant study areas, southeastern Lake Michigan. No fishing was done in January 1973 or February 1974.

Seines -- Seined trout-perch comprised 1% (21 fish) of all trout-perch caught in 1974 standard series fishing, compared with 2% (80 fish) in 1973. Of 111 standard series seining efforts in 1974, 99 resulted in zero catches of trout-perch. During 1973, 78 out of 94 standard series seine catches did not contain trout-perch. The high percentage of zero catches made statistical analysis of 1973-1974 trout-perch seine catches unfeasible both on parametric and nonparametric levels.

Trout-perch rarely inhabited the beach zone even during the spawning season and were more commonly found at 6- and 9-m stations. All trout-perch seined during 1973-1974 were taken at night (Fig. B37 in Jude et al. 1975 and Fig. B66); most were adults but yearlings were also captured. Five yearlings, 40-80 mm, and 75 adults, 90-140 mm, were seined in 1973 (Fig. B38, Jude et al. 1975), while five yearlings, 60-70 mm in length, and

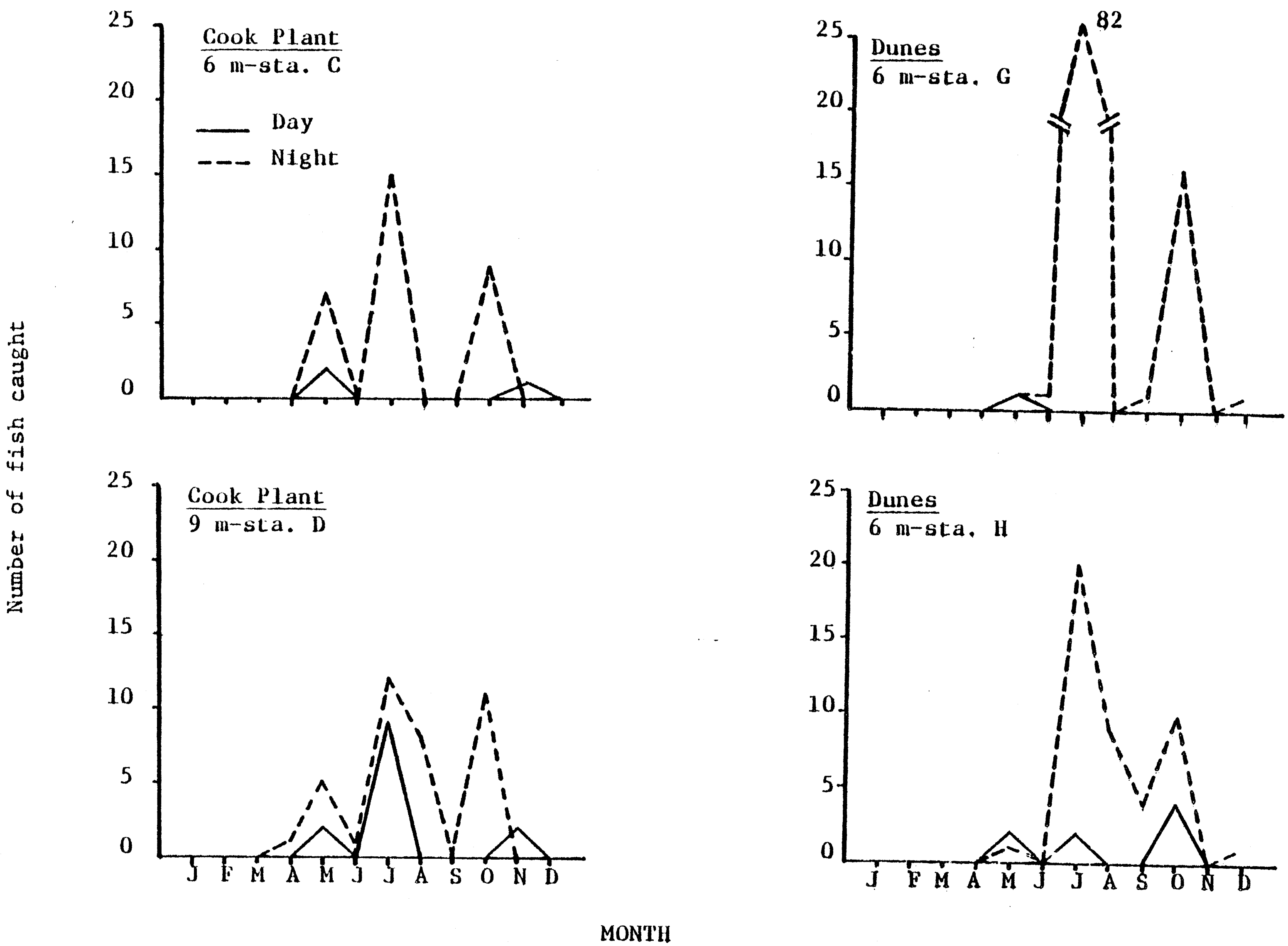


Fig. B65. Number of trout-perch caught in gill nets set during the day and night once per month in January and March to December 1974 at Cook Plant study areas, southeastern Lake Michigan.

17 adults, 90-140 mm, were taken in 1974 (Fig. B67). One of the five trout-perch caught in 1974 larvae tows was found at a beach station (see SECTION C), but no YOY were seined there in either year. There was no apparent preference of trout-perch for a particular seining station in 1974 (Fig. B66), as was found in 1973. From time to time (e.g., May 1973, September 1974) trout-perch were more abundant than usual at seining stations, but reasons for this were not easy to discern. Temperature did not seem to be a factor and comparable large catches were not evident in trawls or gill nets.

Seasonal presence of trout-perch at seining stations was intermittent but generally paralleled seasonal abundance at 6- and 9-m stations. During 1974 trout-perch were seined in April-May, July-September and November. There was no seining in February or December. During January bad weather resulted in an incomplete seining standard series.

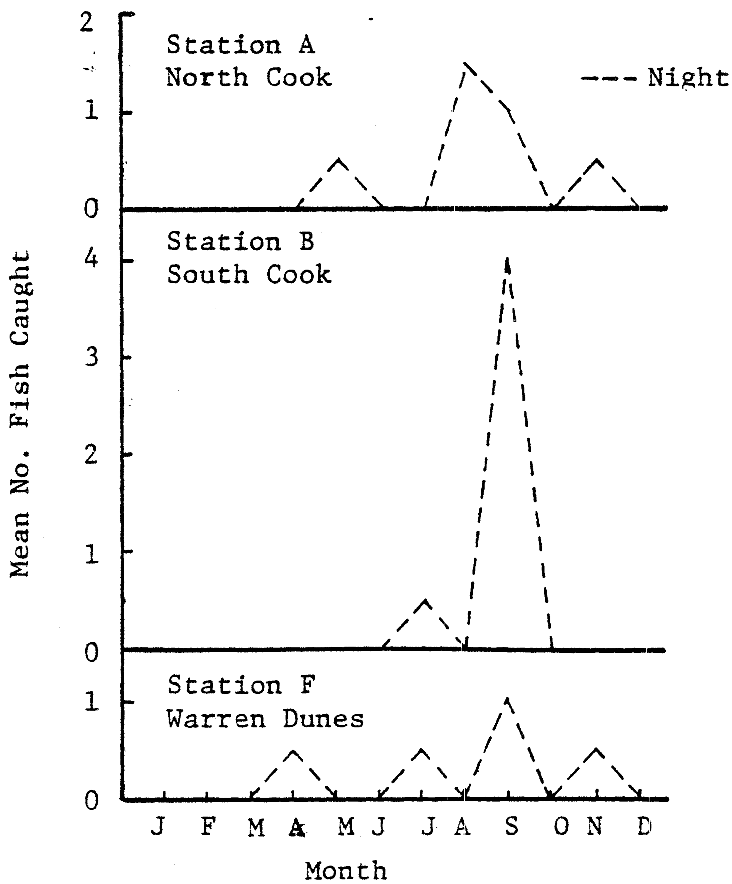


Fig. B66. Mean number of trout-perch caught in seines fished during day and night once per month in January and March-November 1974 at Cook Plant study areas, southeastern Lake Michigan.

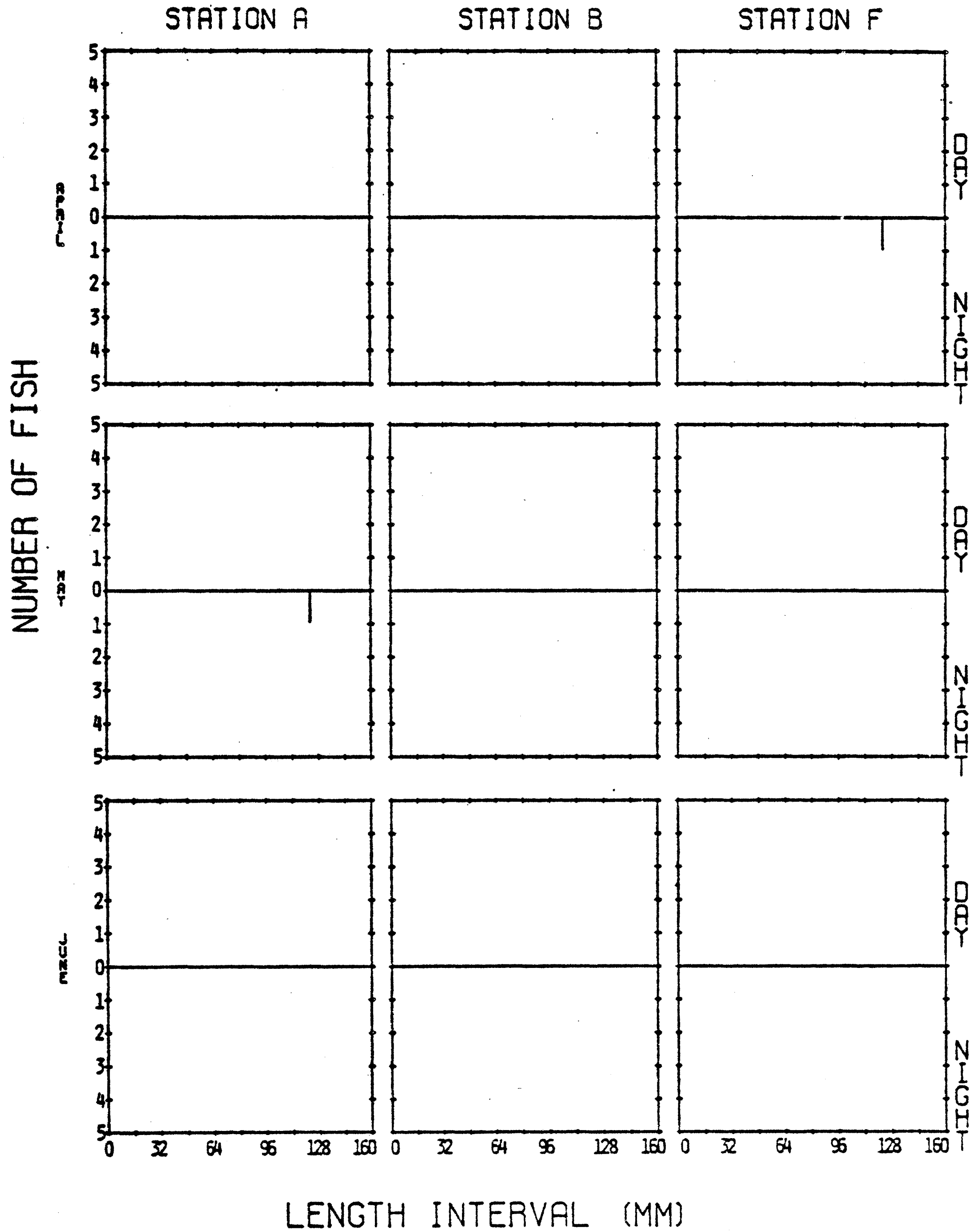


Fig. B67. Length-frequency histograms for trout-perch caught by standard series seining during 1974 at Cook Plant study areas, southeastern Lake Michigan. NF = not fished.

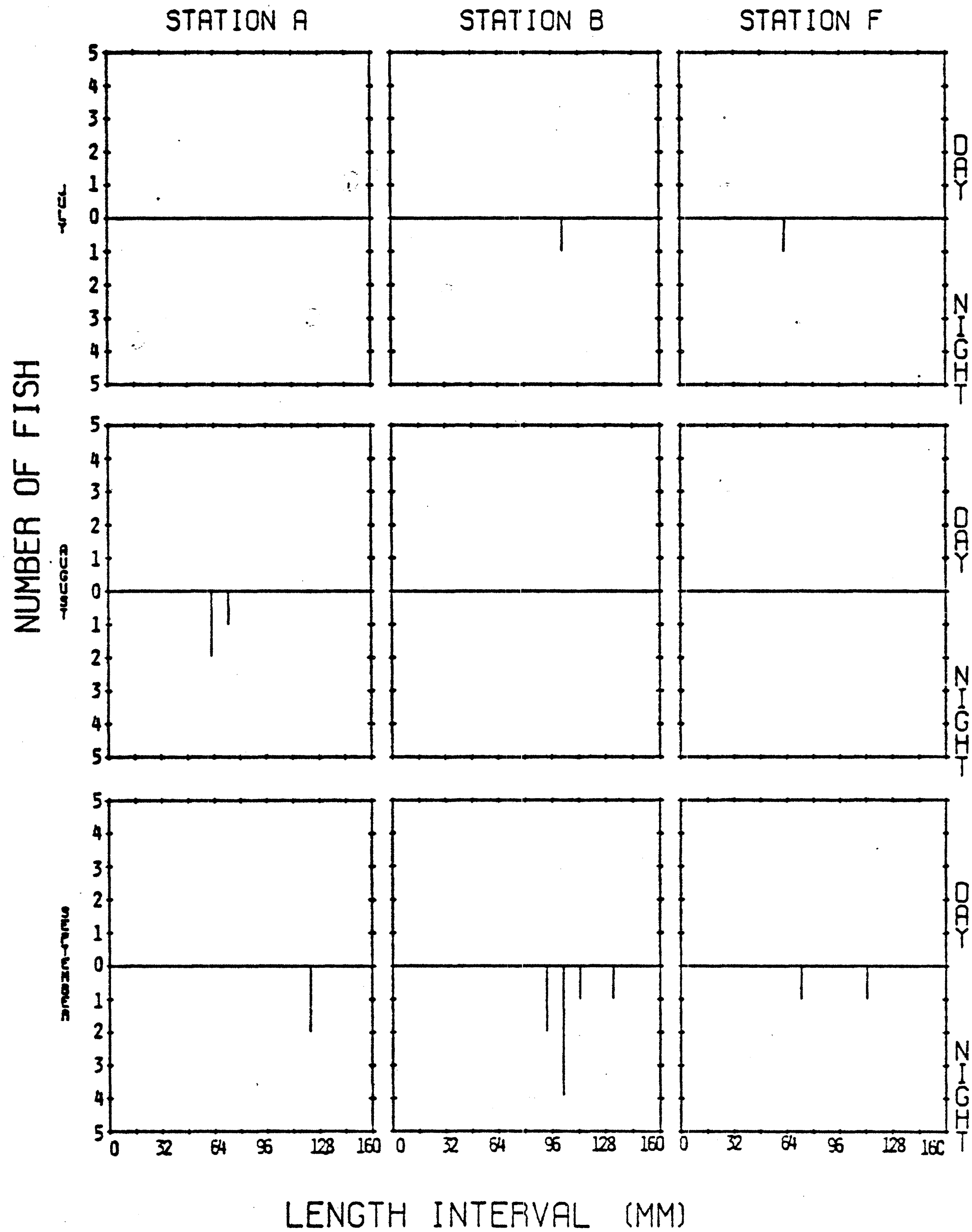


Fig. B67. Continued.

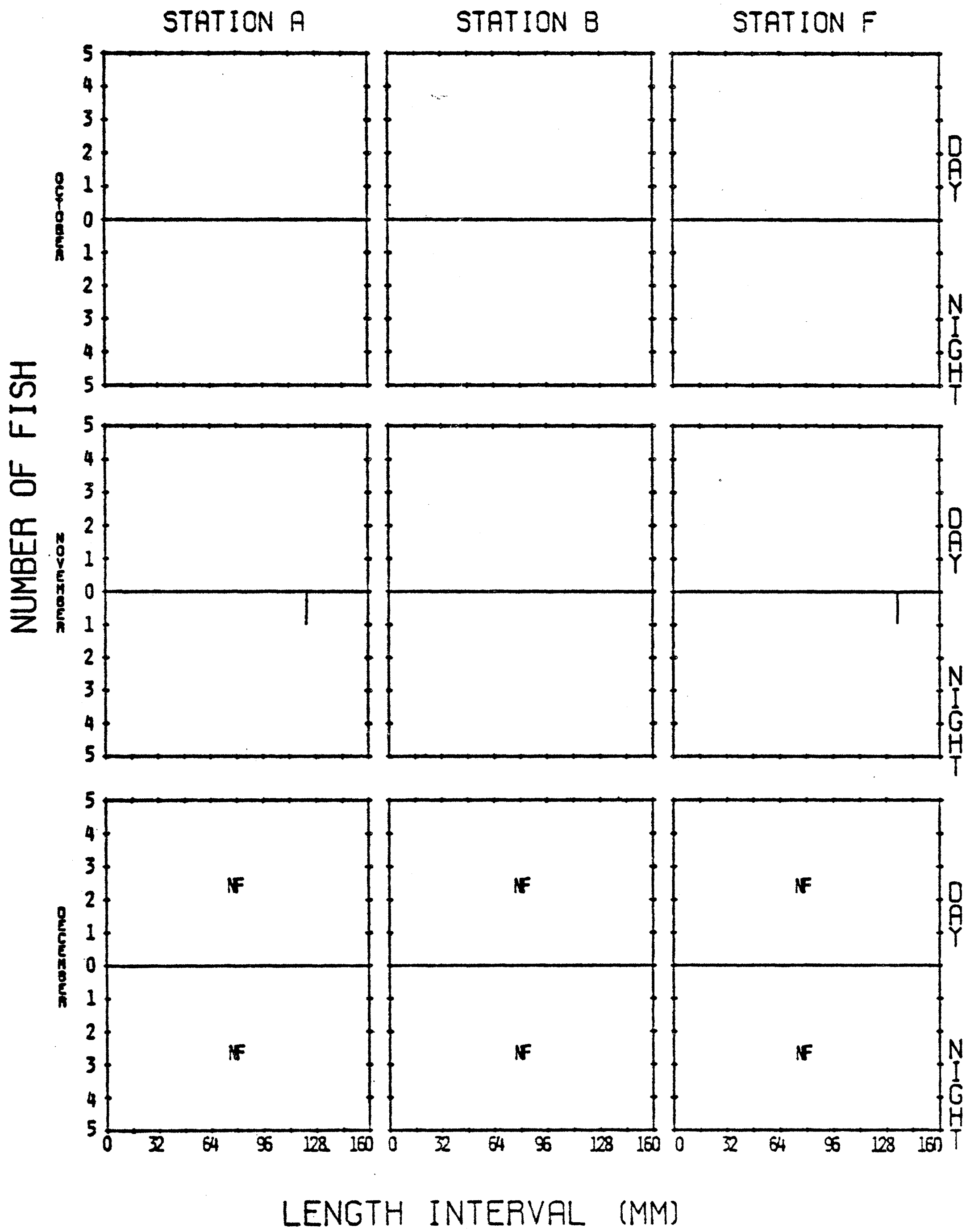


Fig. B67. Continued.

Trout-perch stomach analyses indicated that this species fed largely on benthic organisms, primarily chironomid larvae and amphipods. Benthos sampling in the study area revealed that the benthic community in the 0-3-m zone is very sparse, containing fewer chironomids and amphipods than sediments further offshore (Mozley 1975). It is possible that trout-perch are food-limited in the beach zone and for that reason are found more often in deeper water where numbers of benthic organisms are greater. There is probably competition with other benthic-feeding fishes in the seining area too (spottail shiners, yellow perch) which may limit trout-perch abundance there.

Seasonal distribution by age-size class -- As in 1973 trout-perch were divided into three groups based on total length: YOY, yearlings and adults. Further separation was not reliable due to overlapping length of adult age-groups. Fish scales were not aged due to time constraints. There are several sources that provide age-size class data (House and Wells 1973, Magnuson and Smith 1963, Bostock 1967, Kinney 1950, Trautman 1957). We will emphasize House and Wells (1973) because they worked on southeastern Lake Michigan (near Saugatuck, Benton Harbor and Michigan City). Their data would be expected to most closely represent length ranges and age-size classes encountered in the Cook Plant study area. Relevant age-size class data from their article follows; note total length was used and that mean values are given for the end of a year of growth:

age 0	YOY	49 mm
age 1	Yearling	83 mm
age 2 to 8	Adult	102 mm to 151 mm

Young-of-the-year -- The first 1974 trout-perch YOY (a larva, 6.0 mm) appeared on 25 June; the first 1973 YOY was caught in September. Trout-perch length at hatching is 5.3-6.0 mm (Magnuson and Smith 1963, Fish 1929) so the 1974 specimen was recently hatched. It was taken at beach station A (N Cook) in a larvae tow (SECTION C). Prior to 1974 no trout-perch YOY were caught in larvae tows.

First occurrence of YOY in 1974 standard series fishing may have been in July. Several small trout-perch (30-mm length interval) were trawled and were either early-spawned, fast-growing 1974 YOY, or late-spawned 1973 yearlings (Fig. B63). The ambiguity is due to the extended spawning season of this species in Lake Michigan (May-September). A few ripe-running and spent trout-perch were found during May 1974 (Table B42), so there may have been YOY spawned early enough in 1974 to reach the 30-mm interval (25-34 mm) by July. No YOY were seined in July.

During August at Cook (9 m) and Warren Dunes (6 and 9 m), in September at Cook (9 m) and in November at Cook and Warren Dunes (9 m) additional YOY were trawled (Fig. B63). Their numbers remained too low to indicate preference for station or depth. We caught many of them at night as in 1973. Most YOY during these months were 20-30 mm. Five smaller trout-perch (6.0-18.0 mm) were observed in larvae tows (mostly with the sled) and in

entrainment samples during June (one), August (two), September (one) and November (one) (see SECTIONS C and D). Suspected benthic distribution of YOY (Jude et al. 1975) could not be confirmed because catches of this life stage were low.

Trout-perch YOY remained very scarce in our catches. Because this species comprised less than 2% of all standard series fish (by number) in both years, we did not expect to find many YOY. Unfortunately YOY trout-perch have not been studied extensively and questions of nursery area location, temperature requirements and natural mortality rates are unresolved. Magnuson and Smith (1963) suggested that mortality of eggs and larvae may be unusually high in beach zones of large lakes due to wave action and substrate abrasion. Regarding depth distribution, Fish (1929) found trout-perch larvae out to the 60-m contour in Lake Erie during the summer, though about half of the larvae she captured were at the 3-7-m contours. Magnuson and Smith (1963) reported that YOY occurred first on the bottom at 3-6 m in Red Lake, Minnesota and then moved offshore later in the summer, which may explain why we collected so few.

Yearlings -- The first trout-perch yearling captured during 1974 (40-mm length interval) was trawled at night in April at the 9-m Cook station (Fig. B63). During April, May and June most yearlings were in the 30-50-mm length interval; all were taken in trawls. Larger individuals (50-70 mm) were also collected at this time and may have been yearlings or small adults. There was no observable modal length during these months because of low numbers of yearlings caught and large range in size, the latter resulting from the species' extended spawning season.

In July 1974 trout-perch length frequencies exhibited a mode at 50 mm (Fig. B68) as was found in July 1973 (Jude et al. 1975). The 1974 modal length of 50 mm appeared about a year after the 1973 spawning peak (June-July), so our data agreed closely with the House and Wells (1973) average length of 49 mm at the end of the first year of life. In August and September yearlings occurred in the 60-mm length interval while October yearlings appeared mainly in the 60-80-mm intervals (Fig. B63). No yearlings were caught in November or December.

In 1974 we usually caught more yearlings at night, as in 1973, but predominance of night-caught yearlings did not always occur in 1974. During July the expected diel pattern was reversed (as with adult trout-perch), apparently due to an upwelling (Fig. B63).

Yearling trout-perch depth distribution was difficult to determine. Yearlings appeared somewhat more often at 9 m in May and June trawls (Fig. B63), suggesting that they were mainly at 9 m or further offshore. Our 1973 data indicated that yearlings were at 2-9 m in April and May (Jude et al. 1975). Possibly the late spring in 1974 delayed inshore movement of yearlings. After June, yearlings displayed no distinct depth distribution in our sampling except that most were caught in trawls at 6 and 9 m and were rarely found in the beach zone. These catch data indicated that trout-perch

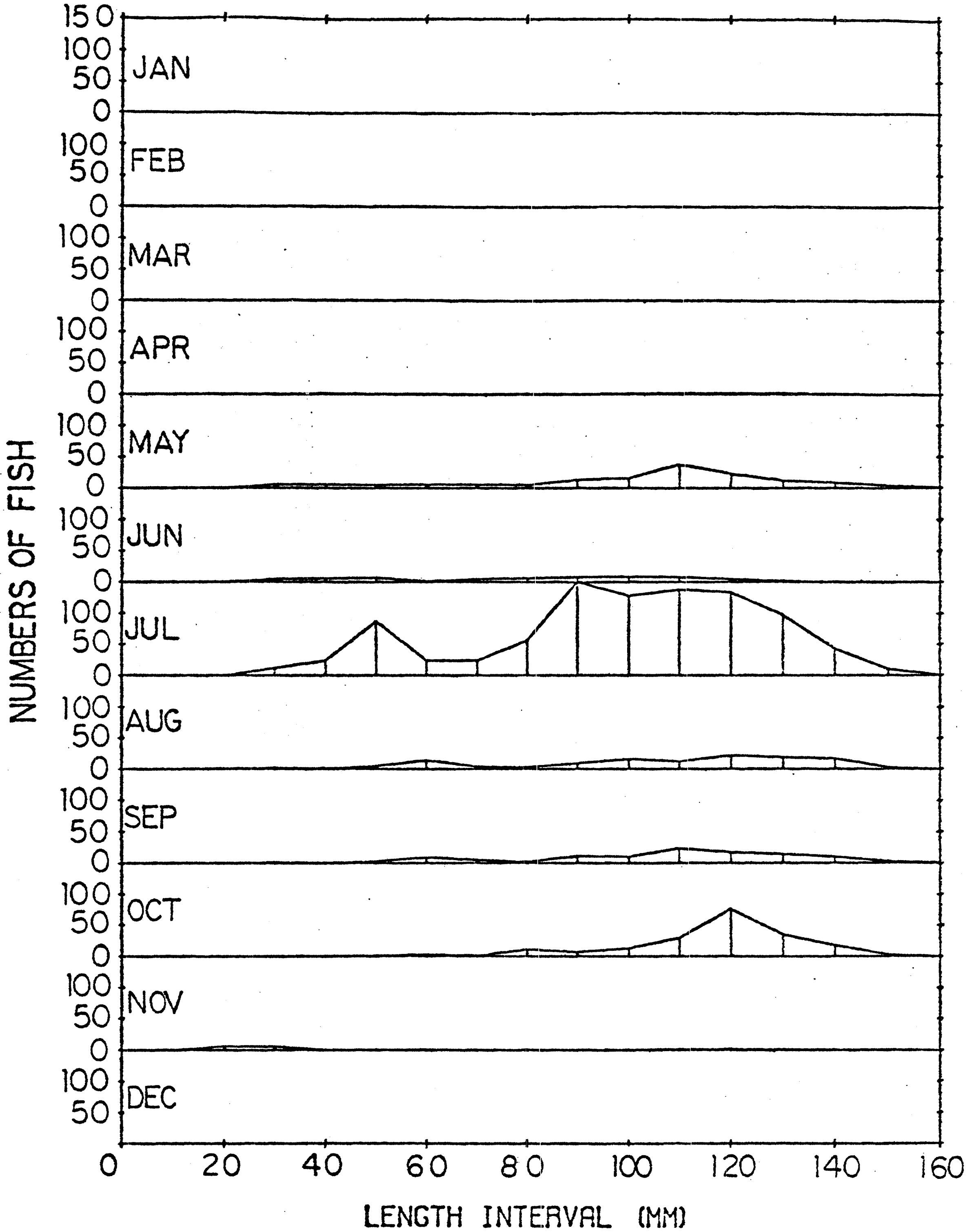


Fig. B68. Composite monthly length-frequency histogram of all trout-perch collected during 1974 at Cook Plant study areas, southeastern Lake Michigan.

may have been more inshore than they were in May and June, though concentrated deeper than the 2-m contour (depth limit of seines). In July, August and September 60-70-mm trout-perch were seined at night (Fig. B68). These may have been yearlings or older fish. Our 1974 data supported the observation in 1973 that yearlings seldom inhabited the beach zone.

Generally yearlings seem to accompany adults inshore during spring and summer. From our data and other sources (House and Wells 1973, Magnuson and Smith 1963, Kinney 1950) we know that trout-perch yearlings are frequently sexually mature, so their movement in the study area could be associated with spawning to some extent. Other information from our study (Fig. B69) indicated that sexually immature trout-perch (probably YOY, some yearlings and a few older fish) came inshore more during the day than at night, the reverse of the pattern that many sexually mature trout-perch followed. Thus yearling distribution related to sexual maturity is understandably not well-defined. Yearlings were not taken in gill nets during 1974, undoubtedly due to their small size.

Adults -- Limited standard series sampling (seines and gill nets) was done in January and March 1974. No fishing was done in February. Few trout-perch were inshore at this time of year and none were taken in standard series efforts. Only two trout-perch were caught before April in 1973 (Jude et al. 1975). Impingement data for 1974 showed that only one trout-perch was taken in January and six in March. Preliminary 1975 and 1976 winter impingement data also indicated that trout-perch were scarce in the study area during January and February, when lake water temperatures

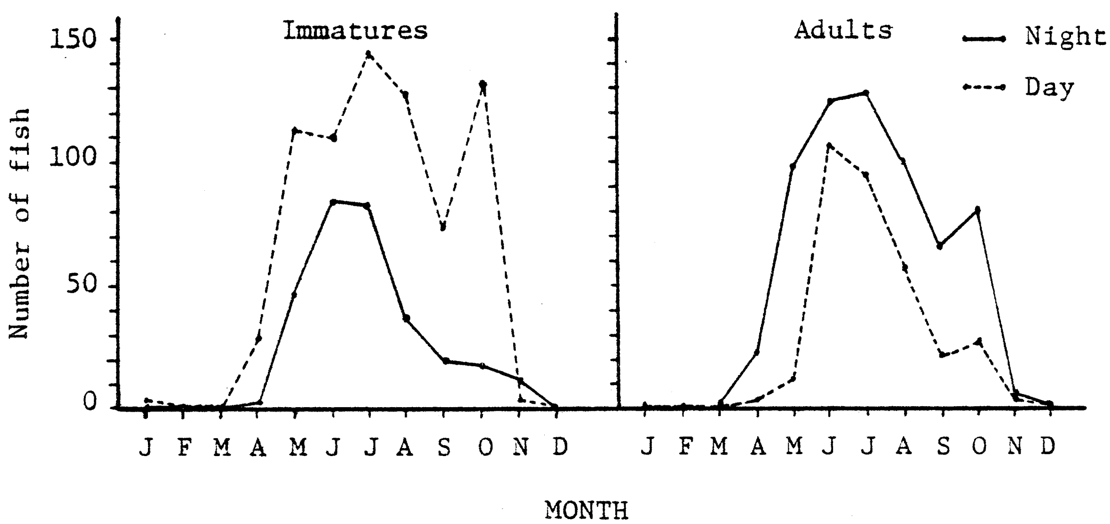


Fig. B69. Monthly day and night standard series, unadjusted catch of immature and adult trout-perch during 1973-1974, at Cook Plant study areas, southeastern Lake Michigan. Catches from all gear types were combined. Classification of adults or immatures was based on gonad conditions.

reach yearly lows (Fig. B6). Wells (1968) fished southeastern Lake Michigan during February and found trout-perch concentrated at 27-37 m. The numbers he trawled were low compared to his trout-perch catches in the same area during warmer months, suggesting that these fish had migrated elsewhere in the lake during February.

Trout-perch first appeared in field samples in April 1974 (Figs. B63, 67, 70). By this time inshore water had begun to warm (Figs. B5 and B15), attracting adults from colder offshore waters. Fewer trout-perch were caught in April 1974 (10) than in April 1973 (47). Later onshore movement of fish in 1974 was thought to be the result of cooler March water temperatures compared to 1973 (Figs. B6 and B15). In both years nearly all trout-perch from April were captured at night.

May 1974 data indicated more extensive utilization of nearshore waters by adult trout-perch than during January-April. Presence of a few ripe-running (1973) and spent (1974) fish in May (Table B43 and Jude et al. 1975, Table B32) marked this month as the beginning of the spawning season for the species in both years. Peak spawning activity occurred later in the year however. Pronounced nocturnal shoreward movement, (as in April), was again observed and in 1974 continued through much of the year. Nocturnal inshore migration is typical of trout-perch (Scott and Crossman 1973, Magnuson and Smith 1963, McPhail and Lindsey 1970, Emery 1973).

The June 1974 adult trout-perch catch was much lower than in June 1973 when the largest standard series catch of trout-perch that year was recorded (1567 in 1973, 55 in 1974). Gonad data from both years (Table B43 and Jude et al. 1975, Table B32) suggested a sizable difference in inshore spawning activity between years. In 1973 spawning occurred in June and to a lesser extent in July, while in 1974 July was the peak month. Similar shifts in peak spawning periods seem to have occurred in 1975-1976, based on preliminary data. Water temperatures in the study area were cooler in June 1974 than in June 1973 (see Figs. B6 and B15). While spawning temperature preferenda for this species have been little studied, it is possible that water temperature may affect trout-perch distribution markedly (Wells 1968). Water temperature is known to be closely related to spawning activity in fishes (Scott and Crossman 1973, Egami and Hosokawa 1973). We believe that the different temperature regimes in 1973 and 1974 contributed significantly to the observed disparity of inshore movement patterns and spawning.

During 1974 more trout-perch were taken in July than in any other month (Figs. B63 and B70). Most July trout-perch were trawled. The larger day catch observed in trawls was atypical of this species. Gonad and temperature data for July (Table B43 and Fig. B15) suggested that the species was at its summer spawning peak and in addition, that the July catch was affected by a strong upwelling. A similar reversal of expected diel distribution occurred at Cook stations (6 and 9 m) in August 1973 during an upwelling (Jude et al. 1975, p. 176).

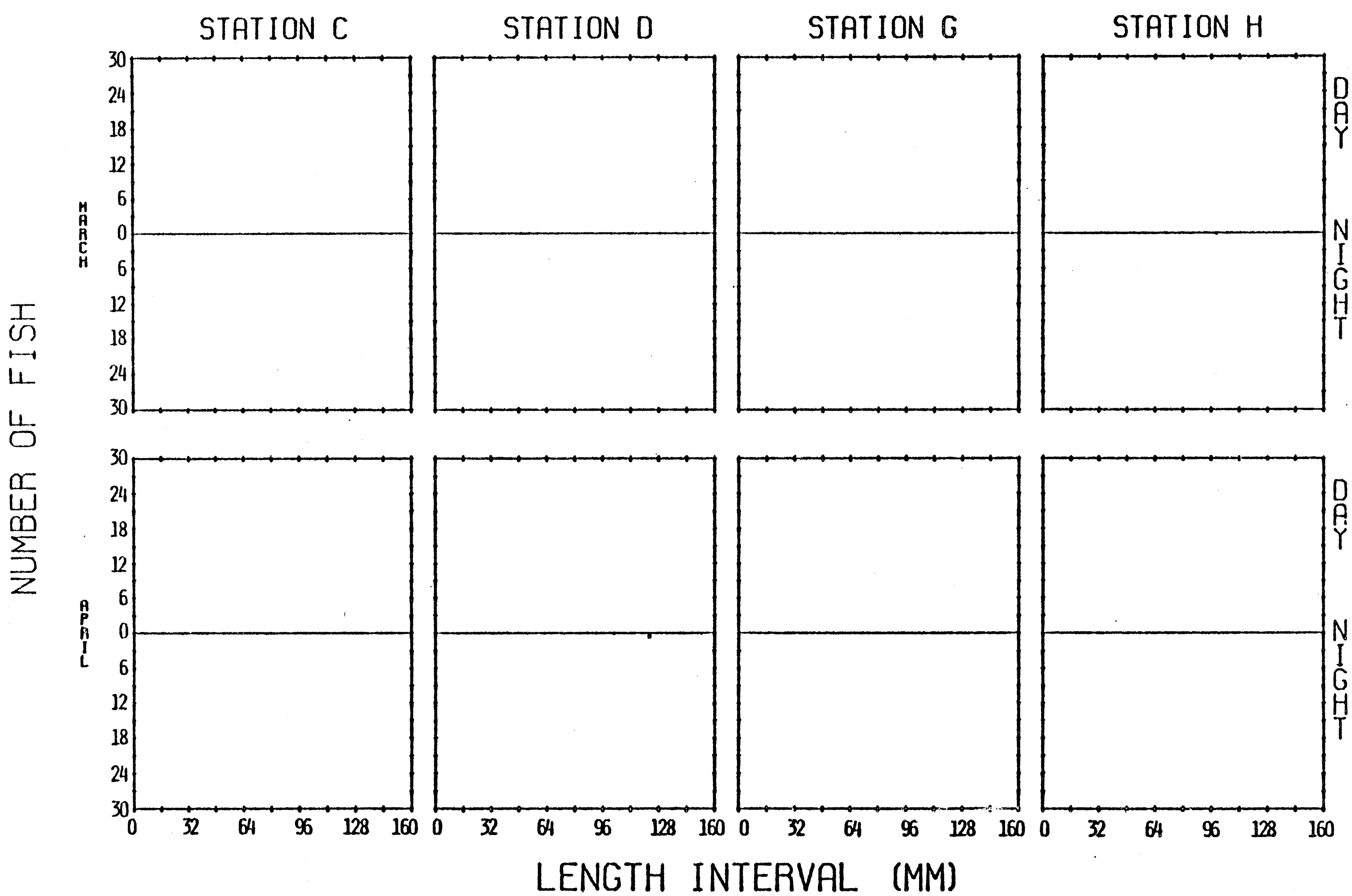


Fig. B70. Length-frequency histograms for trout-perch caught by standard series gillnetting during 1974 at Cook Plant study areas, southeastern Lake Michigan.

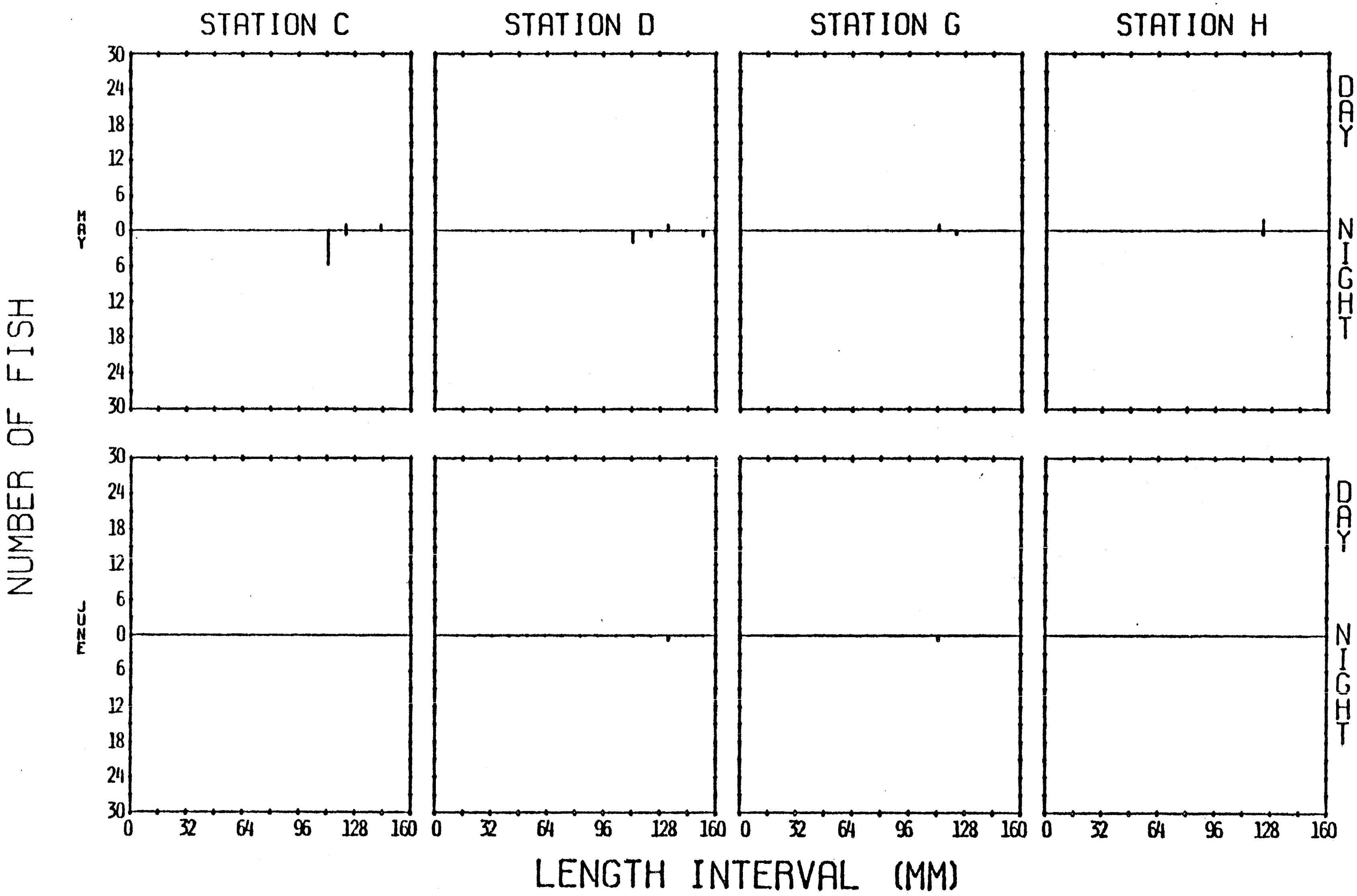


Fig. B70. Continued.

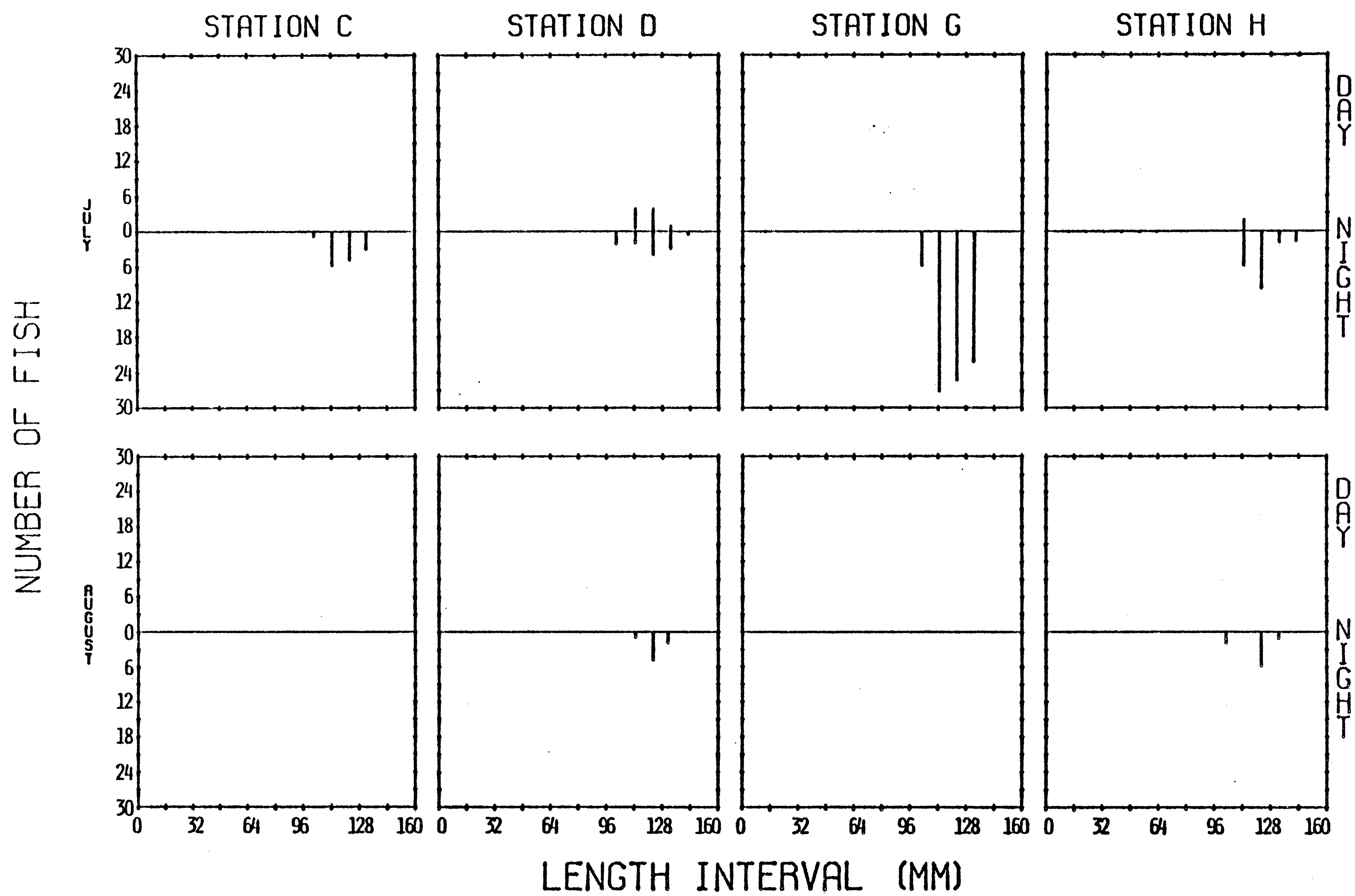
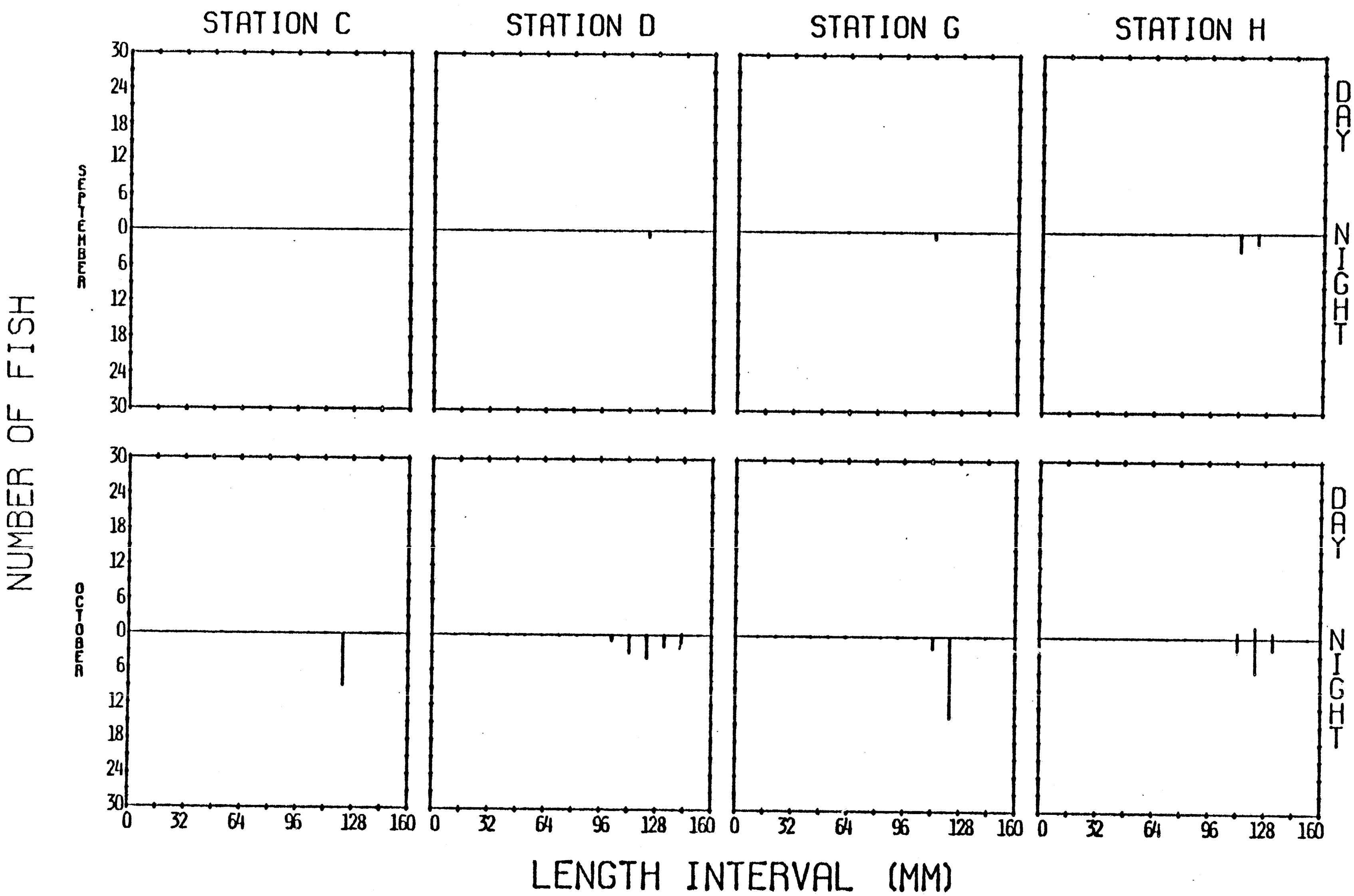


Fig. B70. Continued.



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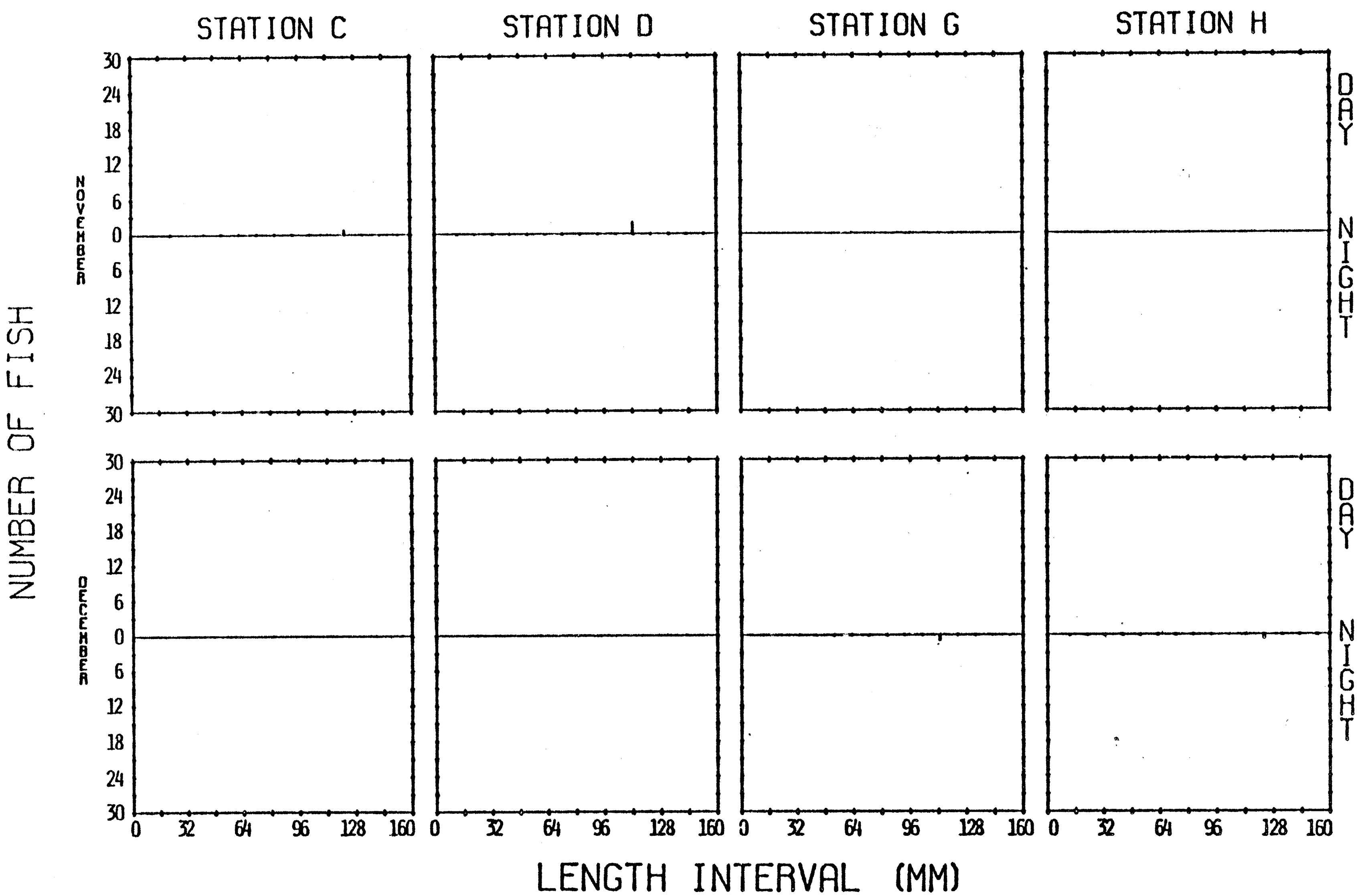

Fig. B70. Continued.

Table B43. Monthly gonad conditions of trout-perch as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1974 at Cook Plant study areas, southeastern Lake Michigan. All fish examined in a month were included except poorly received specimens.

Gonad condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Females												
Poorly dev.				2	2		14	3	4	9	1	1
Mod. dev.	2		2	2	9	1	37	3	28	87	3	
Well dev.	2			4	58	9	134	47	17	2		
Ripe-running					2		4					
Spent					3	7	64	30	26	24		
Males												
Poorly dev.				1	1	2	16	18	13	10		
Mod. dev.			3	3	10	6	44	20	13	31	2	2
Well dev.			1	2	37	12	75	32	12	3		
Ripe-running					1	1						
Spent					1	2	13	5	8	5		
Unable to Distinguish												
						1	9	6	1	3		
Immature												
				1	21	19	90	28	13	4	12	

Gill net catch was responsible for a smaller part of the total July catch than were trawls. Gill net catches seemed to indicate more typical nocturnal activity (Fig. B70) than trawls did, due mainly to different sampling dates for trawling and gillnetting. Night gillnetting and night trawling were both done the evening of July 8-9. Trout-perch were abundant in the study area that night; thus both night trawls and night gill nets yielded large catches of trout-perch. Day trawling was done on July 8 and 9, concomitant with a dense inshore concentration of trout-perch, which resulted in even higher catches of this species than the night gill nets and trawls did. However, day gill nets, which contained low numbers of trout-perch, were set on July 10. By then the inshore concentration of trout-perch observed in the day trawls of July 8 and 9 had probably dispersed, either alongshore or back offshore. This produced lower day gill net catches than night catches, despite the apparently opposite trend in the trawl data. Fish movement during upwellings is swift as well as massive and trout-perch distributions can change considerably even in a few hours (Wells 1968).

In August we observed a slight upwelling at some stations (night gill nets and trawls at 9 m, Cook and Warren Dunes; day trawls at Warren Dunes 9 m). Trout-perch did not appear to react as much as they did during the stronger July upwelling. Typical nocturnal activity was observed and catches generally were more evenly distributed between stations (Figs. B63 and B70) than in July. It was suspected that trout-perch did not respond as extensively to the August upwelling because (a) there were fewer trout-perch in the area since spawning had already peaked earlier in summer and (b) gill net and trawl water temperatures were not as low during the August upwelling as they were in July (Tables B1-3).

The pattern of larger night catches than day catches resumed in August. There were bigger catches at night in 9-m gill nets (Cook and Warren Dunes) and in the 6-m night trawl at Warren Dunes (Figs. B63 and B70) than in other samples. These events did not seem directly attributable to temperature, though the upwelling could have generated the uneven trout-perch distribution. However, variation in catch size of the magnitude observed here was seen at other times when no upwelling was present and was thought to reflect generally clumped distribution of this species in the study area (see also 1974 September and October trawl data, Fig. B63).

In September and October, adults were taken mainly at night in all three gear types (Figs. B63, B67, and B70), as in 1973. Standard series fishing, though incomplete in November and December, suggested that low numbers of trout-perch were present in the study area. One trout-perch was impinged in November and two in December, 1974. Wells (1968) found trout-perch concentrated at 18-22 m in October and 18-31 m in November in southeastern Lake Michigan. However our impingement data for the fall of 1975 and 1976 indicated that large numbers of trout-perch may remain in the study area even into December, perhaps driven inshore by the cooling of offshore waters as winter approaches. Accumulation of warmer epilimnion waters inshore as a result of downwelling may also contribute to large

trout-perch catches earlier in the fall (September-October), before autumn mixis of the lake is complete.

Temperature-catch relationships -- Only very general observations have been made regarding trout-perch responses to water temperature. Literature surveys indicate that spawning temperature preferenda and other temperature limitations have not been examined in detail. Wells (1968) found Lake Michigan trout-perch mostly in 10-16 C water. Magnuson and Smith (1963) noted that trout-perch in Lower Red Lake, Minnesota began spawning after mean air temperature was above 10 C for 44-46 days.

Our gonad data indicated trout-perch began initial spawning activity as early as April (1973) and May (1974) in the study area (Table B32 in Jude et al. 1975, and Table B43). Standard series fishing temperatures in April 1973 averaged 7.5 C and in May 1974 averaged 10.2 C. Peak spawning in 1973 occurred in June and July; water temperatures during gillnetting and trawling averaged 17.9 and 18.7 C respectively in June. In July, water temperatures during gillnetting averaged 16.2 C and during trawling, 19.9 C. In 1974 spawning peaked in July when trawling water temperatures averaged 13.8 C and gillnetting temperatures averaged 15.2 C. Seining temperatures were not considered pertinent because so few trout-perch were seined during the height of the spawning season (one in June-July 1973, two in June-July 1974).

Temperature-catch data (Fig. B71) indicated that trout-perch in 1973 and 1974 were caught most frequently at 16-19.9 C in Cook Plant study areas. Since the majority of trout-perch were taken during June and July, this range was probably a general indicator of spawning temperature preferenda. During times when trout-perch are not spawning, they may prefer lower temperatures. Emery (1973) observed them schooling near the bottom of Lake Huron in Georgian Bay. In daytime they were at or below the thermocline, though at night they moved into shallow water.

Upwellings occur frequently in the study area, especially in summer. In 1974 major upwellings took place in July (gill net and trawl stations) and August (seine stations). Minor upwellings also occurred at offshore (6 and 9 m) stations in August. Reversal of expected nocturnal shoreward movement of trout-perch in July 1974 was suspected to be the result of an upwelling. Stations with colder water temperatures during that month were Cook 9 m (day and night) and Warren Dunes 6 and 9 m (night only). Trawling temperatures at the colder stations were 10.2-11.3 C, while temperatures at warmer stations were 14.8-19.9 C. The warmer stations had noticeably higher catches (Fig. B63). Gill net catches initially appeared not to follow this pattern, but day gill nets were set the day after trawling was completed and therefore were not strictly comparable to trawl catches during the upwelling.

During August 1973 trout-perch nocturnal inshore movement was similarly reversed at Cook stations during a strong upwelling (Jude et al. 1975). At that time there was no clear preference for warmer stations. The September 1973 upwelling produced warmest water temperatures at night, when more

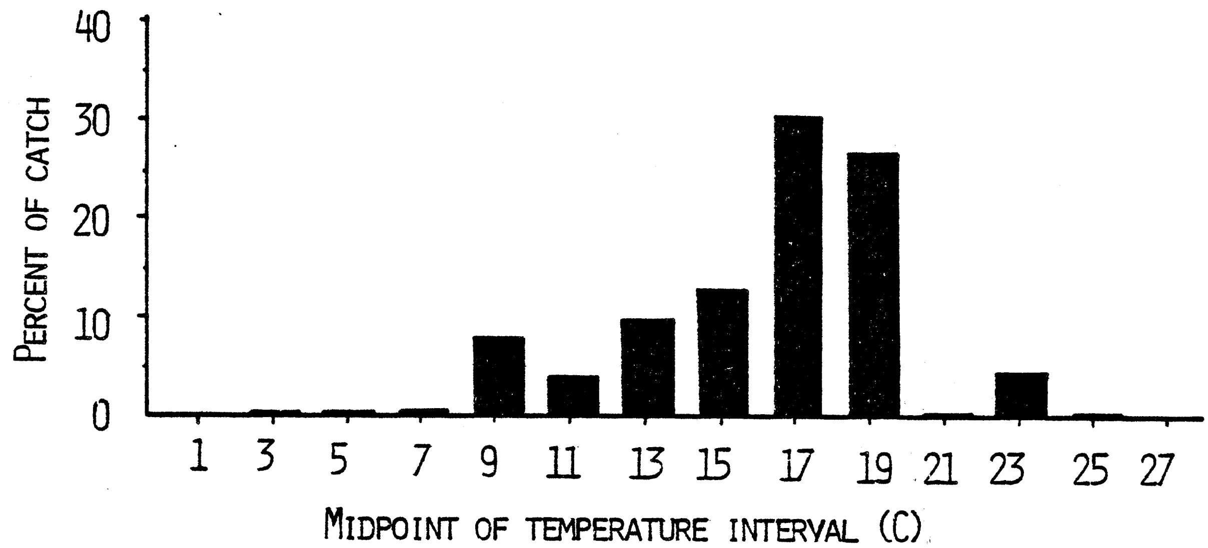

Fig. B71. Percentage of the combined total standard series catch of trout-perch for 1973 and 1974 collected from different temperatures at Cook Plant study areas, southeastern Lake Michigan.

trout-perch were caught (101-night, 68-day). Unfortunately, the warm-water period coincided with the time of nocturnal inshore movement of this species, making it impossible to determine whether trout-perch actually preferred the warmer night temperatures over cooler daytime temperatures. Other upwellings during 1973-1974 fishing were less pronounced and trout-perch showed no definite preference for warmer or cooler stations.

Wells (1968) documented two upwellings in southeastern Lake Michigan during which trout-perch moved into deeper, cooler water. Emery (1970) observed an internal seiche which caused an 11.7 C drop in Lake bottom temperature in Georgian Bay. Trout-perch remained in the area although other species moved away. Our contrary observation of trout-perch concentrated at warmer stations in July 1974 could be associated with spawning which was occurring at that time. During spawning trout-perch may prefer warmer water while at other times the species may be indifferent to cooler water or may even be attracted to it. Much remains to be learned about the temperature preferences of this species.

There was no apparent relationship between trout-perch age-size classes and temperature in the 1973-1974 data (Fig. B72) which is in contrast to alewife, spottail shiner and smelt. These species exhibited a definite relationship between size of fish and water temperature in which it was caught. For these fish, younger individuals were often taken at warmer temperatures than adults of the same species.

Field catch as a preoperational data base -- Since trout-perch are primarily a benthic species their population was sampled representatively by our bottom trawls and seines. Gill net catches of trout-perch were generally low and were not highly sensitive indicators of changes in

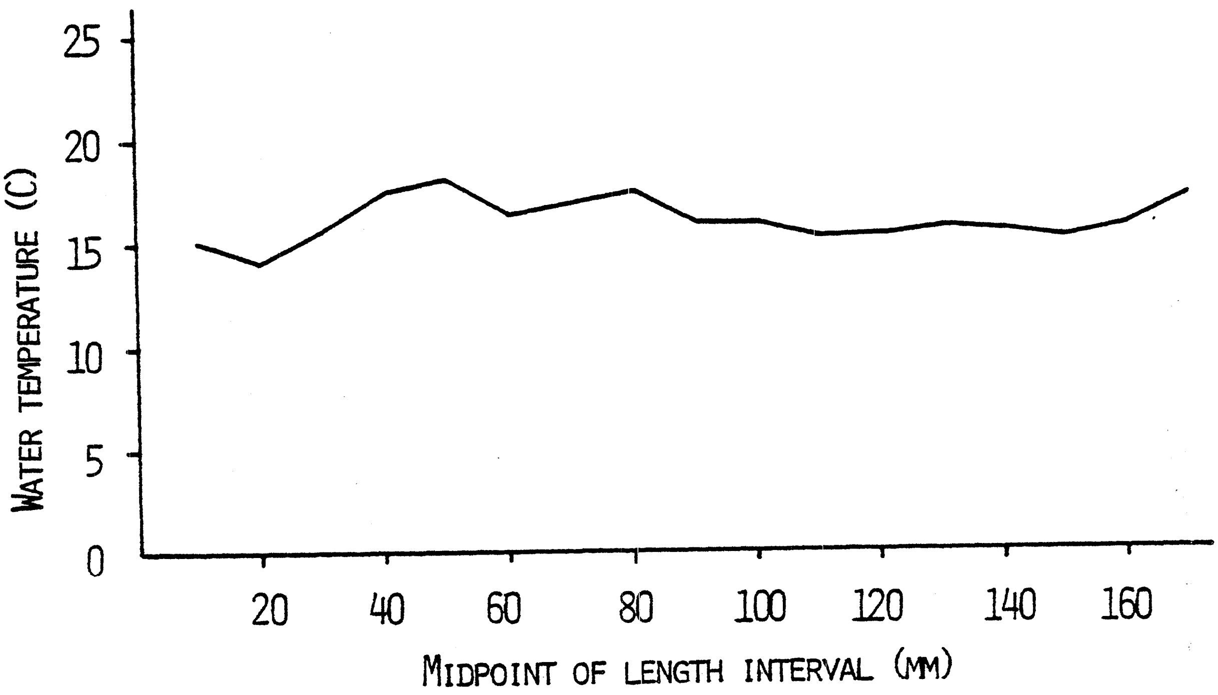

Fig. B72. Mean temperature at which different sizes of trout-perch were captured during 1973 and 1974 in standard series nets at Cook Plant survey areas, southeastern Lake Michigan.

trout-perch abundance because this gear underestimates trout-perch populations because of mesh bias. Seine catches were also very low and we are not sure why this species avoids the beach zone though low abundance of benthic food organisms may be the cause. In any event, increased habitation of the beach zone by trout-perch during operational years would be unusual and if it occurred only at Cook stations, not Warren Dunes, the possibility of a plant effect should be considered.

Statistical tests as well as non-statistical evaluation of trout-perch data revealed the pronounced nocturnal shoreward movement characteristic of this species. Reasons for this diel activity pattern are unknown and nocturnal migration usually occurs independently of water temperature (except in winter) or spawning season. Some sources report that this movement is associated with nocturnal feeding but evidence is not conclusive. While trout-perch nocturnal shoreward migration in preoperational years was occasionally interrupted, it was generally a predictable part of trout-perch behavior in the study areas. Disruption of this diel pattern for an extended period of time would be considered atypical and a possible consequence of plant operation, provided a similar disruption did not occur at our control stations.

Seasonal patterns of trout-perch abundance were relatively predictable and were undoubtedly affected by water temperature, as with other species. Unfortunately so little is known of trout-perch temperature preference that only general inferences could be made about the relationship between

trout-perch seasonal abundance in the study areas and ambient temperature regimes. YOY trout-perch did not exhibit the marked preference for warmer water that YOY of many other species did, thus extensive attraction of trout-perch YOY to the heated plume does not seem likely during the April-October period.

DEPTH, AREA and YEAR factors were highly variable in trout-perch abundance data and their variability was difficult to explain biologically. Both the magnitude of variation in these factors and our uncertainty as to the causes of this variation will make it difficult to assess plant impact with respect to YEAR, DEPTH and AREA changes in trout-perch abundance.

During preoperational years no die-offs of trout-perch were noted in the study areas. Die-offs of this species, interpreted as post-spawning mortality, have, however, been documented in the literature, (Magnuson and Smith 1963; Kinney 1950). Thus any die-offs which might happen during operational years will have to be evaluated with the possibility of natural mortality in mind, as well as plant impact.

Less Abundant Species

Johnny Darter --

Johnny darters were the sixth most abundant fish caught in 1973 (see Table B6); the following is a brief summary of 1973 data. Darters were caught from April through October, mostly by trawling (201 caught by trawls, six by seines). Trawl data showed this species was caught more often at night and was more abundant at station C (6 m S Cook) compared to the other three trawling stations. Size range of darters caught in 1973 was 19 mm (0.01 g) to 76 mm (3.4 g); most were 35-64 mm (77% of the total catch). Gonad data indicated that spawning occurred in May and June.

As was found in 1973, johnny darters were the sixth most abundant species caught in 1974 (see Table B9). They were caught during every month that trawling occurred--April to November. Trawl catches accounted for 289 fish while four were caught seining. None were gillnetted. Monthly catches varied considerably, with largest catches occurring in May, June and July (82% of the total catch). These large catches were probably due to increased activity and concentration of fish inshore because of spawning activities.

Gonad data for 1974 revealed that spawning occurred during May, June and possibly July (Table B44). The possibility that some spawning occurred in July 1974 may indicate that spawning was more extended in 1974 or possibly occurred slightly later in the year.

More darters were caught by standard series nets in 1974 (293) than in 1973 (207) (Tables B6 and B9). Some of this increase was due to greater fishing effort in 1974; night trawling was performed in November 1974 whereas no trawling occurred during November 1973. But only 14 fish were caught in November 1974, which still leaves 72 more fish caught during other

Table B44. Monthly gonad conditions of johnny darters captured during 1974 in southeastern Lake Michigan. All fish examined in a month were included except poorly received specimens.

Gonad Condition	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
				Females				
Poorly dev.		1		3		8	1	2
Mod. dev.	2	6	3	6	2	2	9	1
Well dev.		35	23	17		2		
Ripe-run.		2		1				
Spent		2	1	7	2	13		
				Males				
Poorly dev.			3	7	4	4		
Mod. dev.	3	20	4	13	4		4	
Well dev.		14	1	2	1	2	1	1
Ripe-run.			1					
Spent				1	2		1	
				Unable to distinguish				
		4	11	18	2	3	2	10
				Immature				
		9	41	30	3	8	6	

months of 1974 compared to 1973. This 35% increase in catch in 1974 was possibly more than just natural sampling variation. We suspect that the population may have increased in the study area during 1974.

Part of the suspected population increase may be due to a localized population of darters being established in the riprap around the intake and discharge structures at the Cook Plant. Diving observations have indicated that darters utilized the riprap extensively as habitat (Dorr 1974b, Dorr and Miller 1975). In 1973 riprap was being layed down while in 1974 construction on the underwater structures was complete. Darters, therefore were just beginning to inhabit the riprap in 1973 while in 1974 a population probably had established itself. This may account for some of the increased 1974 catch at Cook, but more fish were also caught at the control area (Warren Dunes) in 1974.

Comparing trawl data from April to October for the 2 yr shows the increased 1974 catch was proportionally greater at Warren Dunes (58%) than Cook (25%) although the absolute increase was similar for both areas (35 and 33 fish respectively). We believe this increased catch was due to a population increase. Reasons for the population increase are undetermined, but we can speculate that possibly spawning success was greater in 1973 than previous years. While few YOY were collected in 1973, many appeared in 1974 catches as yearlings. Most YOY are too small to be adequately sampled by our gear mesh sizes.

A comparison of yearling catches between the 2 yr also indicates the 1973 year class was larger than the 1972 year class (compare Table B34 in Jude et al. 1975 and Table B45 in this report.) Although we did not age johnny darters, we can estimate size of yearlings at approximately 30-40 mm from data of Raney and Lachner (1943) for the Susquehanna River, New York, and Karr (1963) for the Des Moines River, Iowa, who showed johnny darters reached 24-48-mm SL (standard length) and 28-52-mm TL respectively during the first year of life. Our data during May, June and July for fish 25-44-mm TL showed 47 yearlings caught in 1973 and 89 in 1974. This increase accounts for some of the population increase in 1974 over 1973.

More larger fish (65+ mm) were caught in 1974 (Table B34 in Jude et al. 1975 and Table B45 in this report). Data for April through October show 15% (31 fish) of the catch in 1973 were fish 65+ mm and 20% (57 fish) of the catch in 1974 were 65+ mm. The cause for this difference is unknown.

Scott and Crossman (1973) indicate that males grow to larger sizes than females. Our data for both years also suggest this size difference. There were 32 male and 24 female fish in the 70+ mm size range. Largest fish caught during both years was an 82-mm (6.0 g) male. Although largest fish were predominantly males, more females were caught during both years. The sex ratio did not change significantly during the 2 yr (66% females in 1973 and 62% in 1974).

Trawl data for the 2 yr revealed darters to be most abundant at station

Table B45. Length-frequency distribution of johnny darters caught in standard series nets during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

Length interval	1974								Totals	
(mm)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	1974	1973
15-24					1				1	1
25-34		3	16	2		3	2	3	29	15
35-44		5	30	33		1	5	4	78	48
45-54		10	22	16	2	1	2	1	54	45
55-64	1	37	12	6	2	2	8	4	72	67
65-74	4	34	6	3	1		4	2	54	30
75-84		4					1		5	1
Totals	5	93	86	60	6	7	22	14	293	207

C (6 m-S Cook) at night (Table B46). For both years station C catches constituted 36% of the total catch from the four trawling stations. As mentioned earlier we suspect there is a localized population of darters on

Table B46. Numbers of johnny darters caught by standard series trawls at the four Cook Plant study area stations, southeastern Lake Michigan, April through October 1973 and 1974.

	1973				1974				
	Stations				Stations				
	Cook		Warren Dunes		Cook		Warren Dunes		
	C-6 m	D-9 m	G-6 m	H-9 m	C-6 m	D-9 m	G-6 m	H-9 m	Totals
Day	15	21	6	11	11	10	19	21	114
Night	72	22	25	29	99	43	32	40	362

the riprap. These fish may be seeking spawning areas or feeding at night and thereby increasing catches at station C. Proportionally the largest night catches at station C occurred during May, June and July--months when spawning occurred. The above conclusion is quite speculative; catches at station D (9 m-S Cook), which is as close as station C is to the riprap, were not very abundant especially in May, June and July. Possibly the depth difference between the two stations may account for some of this variation.

Trawl catches for the 2 yr at Warren Dunes suggested that there were more darters at the deeper station (H) both day and night than at the shallower station G (Table B46). This depth distribution difference did not occur at Cook Plant stations.

Trawl data clearly showed increased catches at night (Table B46). Darters are possibly more active at night, although daytime net avoidance may have caused the difference. Feeding data for the 2 yr did not demonstrate a very significant day-night difference. Of the fish caught at night 86% had stomachs with food in them as opposed to 71% for day-caught fish. These high percentages suggest darters were feeding both day and night. Emery (1973) observed (via SCUBA diving) johnny darters in Georgian Bay, Lake Huron feeding both day and night, but more often during the day. He also observed that at night movement was slower and abundance in shallow water increased. Our higher night catches indicated that abundance in the study areas is probably greater at night, but daytime net avoidance may also play a part.

Although we found johnny darters to be quite common in the inshore area, a large part or at least some of the population may reside in deeper water. Wells (1968) caught 19 johnny darters in a southeastern Lake Michigan trawling study from stations located in water 13 to 64 m; however, the majority were caught at stations 22 to 31 m. These limited data indicate that darters are not restricted just to shallow depths. We performed one series of trawls from 6 to 21 m in 3-m increments of depth on June 19, 1973 (see Table B14), but only caught darters at 9 m. Emery (1973) found johnny darters in Georgian Bay, Lake Huron from 8 to 12 m. In the Apostle Islands region of Lake Superior, Dryer (1966) did not observe johnny darters below 35 m and the vast majority (96%) were taken at depths less than 18 m. General accounts in the literature indicated that johnny darters preferred shallow inshore waters (Scott and Crossman 1973), but the seasonal depth distribution of this species in large lakes is still largely unknown.

Darters were caught only from April to November, but we believe these fish are probably present inshore during almost all months of the year. Trawling was not performed during other months of 1973-1974. Since darters were not caught by gill nets, we can not exclude the fishes' presence during other months of the year. In 1975 trawling was performed in December and some darters were caught. Plant impingement data for 1975 showed one darter was collected in January, none in February and March, while some were collected during every other month of the year (see SECTION E). Ten darters collected by seining indicate the fish do utilize the beach zone at times

but only occasionally during warmer months.

Johnny darters captured during both years were taken in water temperatures between 6 and 23.9 C (Fig. B73). This wide temperature range indicated that darters are probably present in the study area throughout the year. Although no definite temperature preference can be ascertained, data indicate that darters probably do not migrate extensively to waters of preferred temperature, but remain in a limited area and are thus caught over a wide temperature range.

In 1973 a large portion of the darter catch occurred at 21 C, while in 1974 two large portions occurred at 9 and 15 C (Fig. B73). These peaks were the result of large catches which occurred predominantly during spawning months of May, June and July (1974 only). These large catches are therefore not directly indicative of thermal preference, but rather of other biological functions, i.e., spawning.

Temperature data illustrated that largest fish were caught at lower temperatures than small fish during both years (Fig. B74). This relationship is probably the result of larger adults preferring lower temperatures and possibly being more stenothermal than smaller fish. Smaller alewives, spottail shiners and yellow perch were also caught in warmer temperatures than larger fish (see Alewife, Spottail Shiner and Yellow Perch). Figure B74 also demonstrates that darters were caught in warmer temperatures in 1973 than in 1974 because temperatures encountered during sampling were warmer in 1973.

As in 1973, divers in 1974 observed johnny darters in the riprap around the intake and discharge structures (Dorr and Miller 1975). These observations revealed that the fish have established a considerable population in the riprap and evidently prefer this rock habitat to the more typical sand bottom in the study area.

Slimy Sculpin --

As in 1973, difficulty in distinguishing mottled sculpins from slimy sculpins led us to group the two together as "slimy sculpins" (see Laboratory Analysis of Fish for a discussion of identification problems).

In 1973, 80 sculpins (0.04% of the total catch) were caught in standard series sampling (see Table B6). In 1974, 272 sculpins (0.24% of the total standard series catch) were taken (see Table B9), an increase of 340%. Most of this increase was accounted for by consistently larger catches at Cook Plant stations. We suspect the riprap around the intake and discharge structures (which was not completely in place until the end of 1973) provided a favorable habitat for a burgeoning local population, which is supported by the observations of SCUBA divers (Dorr 1974b, Dorr and Miller 1975) and by the high incidence of sculpins in collections from Cook Plant traveling screens. Sculpins were frequently observed by divers in the area of the intakes. The fish were commonly hiding among the rocks of the riprap

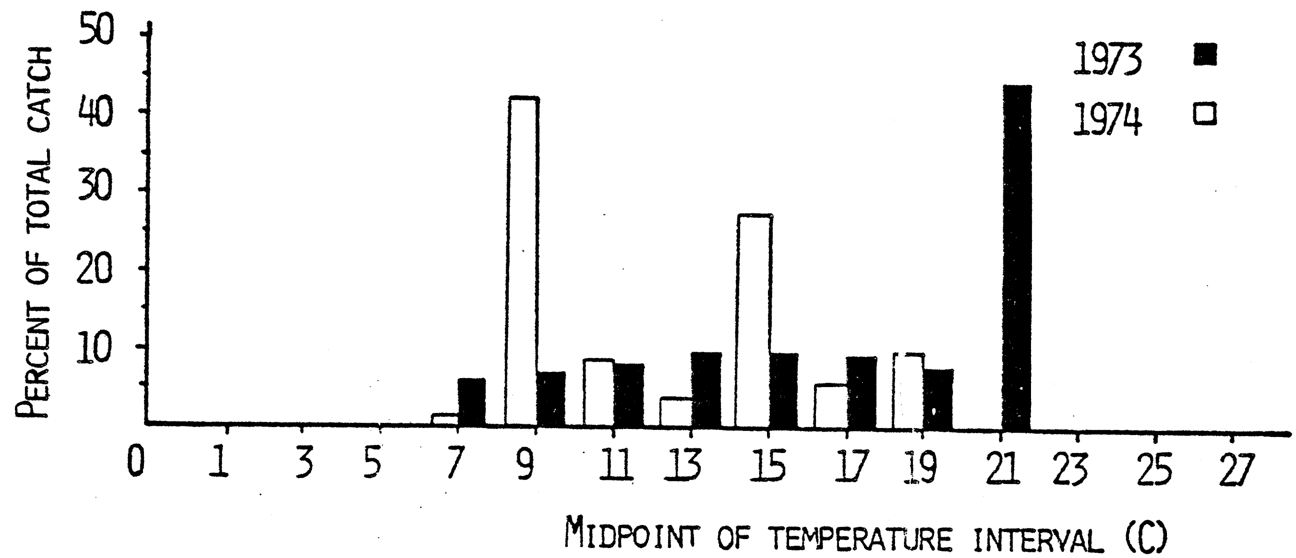

Fig. B73. Percentage of 1973 and 1974 total standard series catches of johnny darters collected from different water temperatures at Cook Plant study areas.

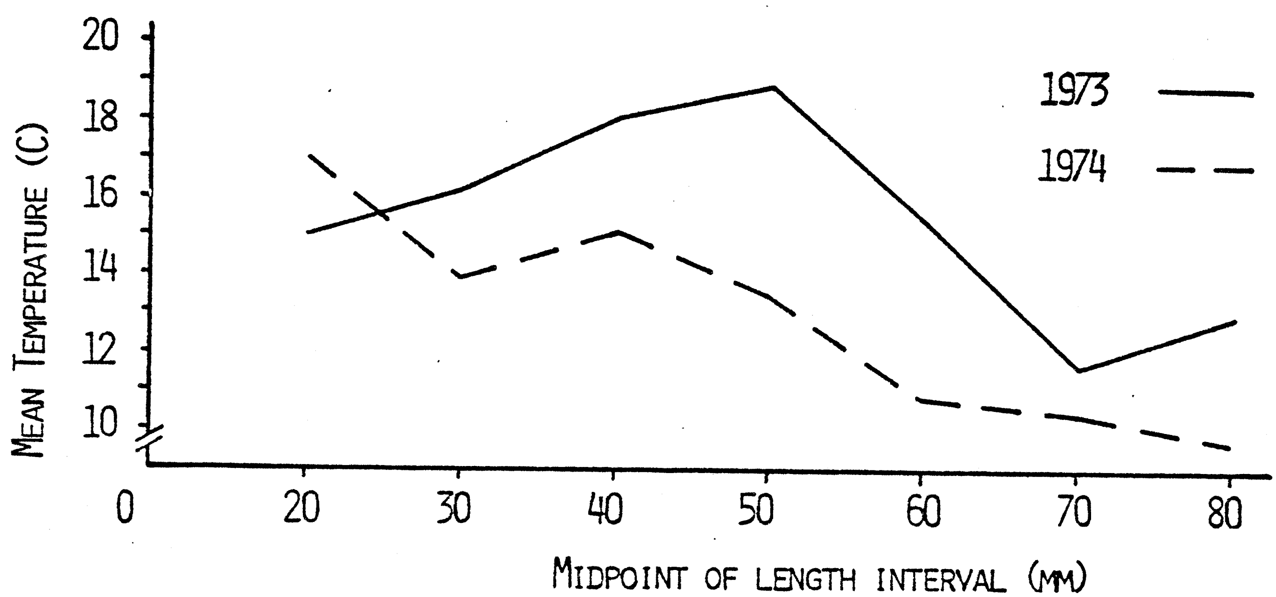

Fig. B74. Mean temperature at which different sizes of johnny darters were captured during 1973 and 1974 in standard series seines and trawls at Cook Plant study areas.

or resting on the top surface of the structure. In May 1974, sculpin eggs were collected from the riprap and hatched in the laboratory, confirming use of the area for spawning. In 1974, 751 sculpins were collected from the traveling screens making them the second most abundant fish impinged (see SECTION E). Preliminary 1975 data showed a somewhat lower relative abundance of sculpins in impingement catches. Erratic pumping probably caused 1974 to be an exceptional year in this respect.

Though field collections most months at Warren Dunes were not significantly larger in 1974 when compared with 1973, there was a seven-fold increase in numbers collected in April 1974 (Fig. B75). As fishing effort was the same both years, this increase is unexplainable at this time.

Appearance of large numbers of sculpins in April of both years and at both areas was probably due to a shoreward movement of the population for spawning, followed by a return to deeper water during warmer months. In trawling studies in Lake Michigan, Wells (1968) found a similar shoreward movement of sculpins in April. Rottiers' (1965) study of slimy sculpins showed spawning began prior to May 5 and was complete by May 23. Our own gonad data from 1973 and 1974 also suggest that spawning began in April, as most fish caught this month had well developed gonads with some ripe-running females and an occasional spent individual (Table B47). Lake temperatures in April also were compatible with values recorded in the literature in relation to sculpin spawning. Temperatures at trawling stations ranged from 6.2 to 7.6 C in 1973 and from 6.0 to 8.0 C in 1974 (see Table B1). Rottiers (1965) caught most of his ripe specimens from Lake Michigan in April when temperature was 6.0 C. Koster (1936) found spawning began at 4.5 C in Cayuga Lake, New York and 10.0 C in Beaver Brook drainage, New York. By May most sculpins we caught were spent or sex could not be distinguished (probably also spent individuals). Sculpin larvae were found in late June 1974 sled tows at 3 m and at station D (9 m-S Cook) from mid-June through mid-July (see SECTION C). YOY sculpins around 20 mm appeared in July trawl catches at Cook stations D and C (Fig. B76).

The sculpin population diminished and almost disappeared from the area during warmer months of 1973 at both the Cook Plant and Warren Dunes, and at Warren Dunes in 1974 (Fig. B75). This was almost certainly due to avoidance of warmer temperatures by sculpins. Wells (1968) seldom collected sculpins in water above 10 C. In June 1973, trawling was done at 3-m intervals from 6 to 21 m off the Cook Plant (see Table B14). The thermocline was between 9 m and 12 m. All sculpins were taken at depths 12 m or greater and at temperatures 9 C or less. Most were collected at 21 m where the temperature was 7.2 C. Our standard series temperature-catch relationships showed most sculpins were caught at temperatures between 6.0 and 9.9 C (Table B48). In 1973 only three fish were collected at temperatures greater than 15.9 C. Those which were collected at warmer temperatures in 1974 were almost entirely from Cook Plant stations, further evidence that this is a local population remaining near the riprap even in warmer weather.

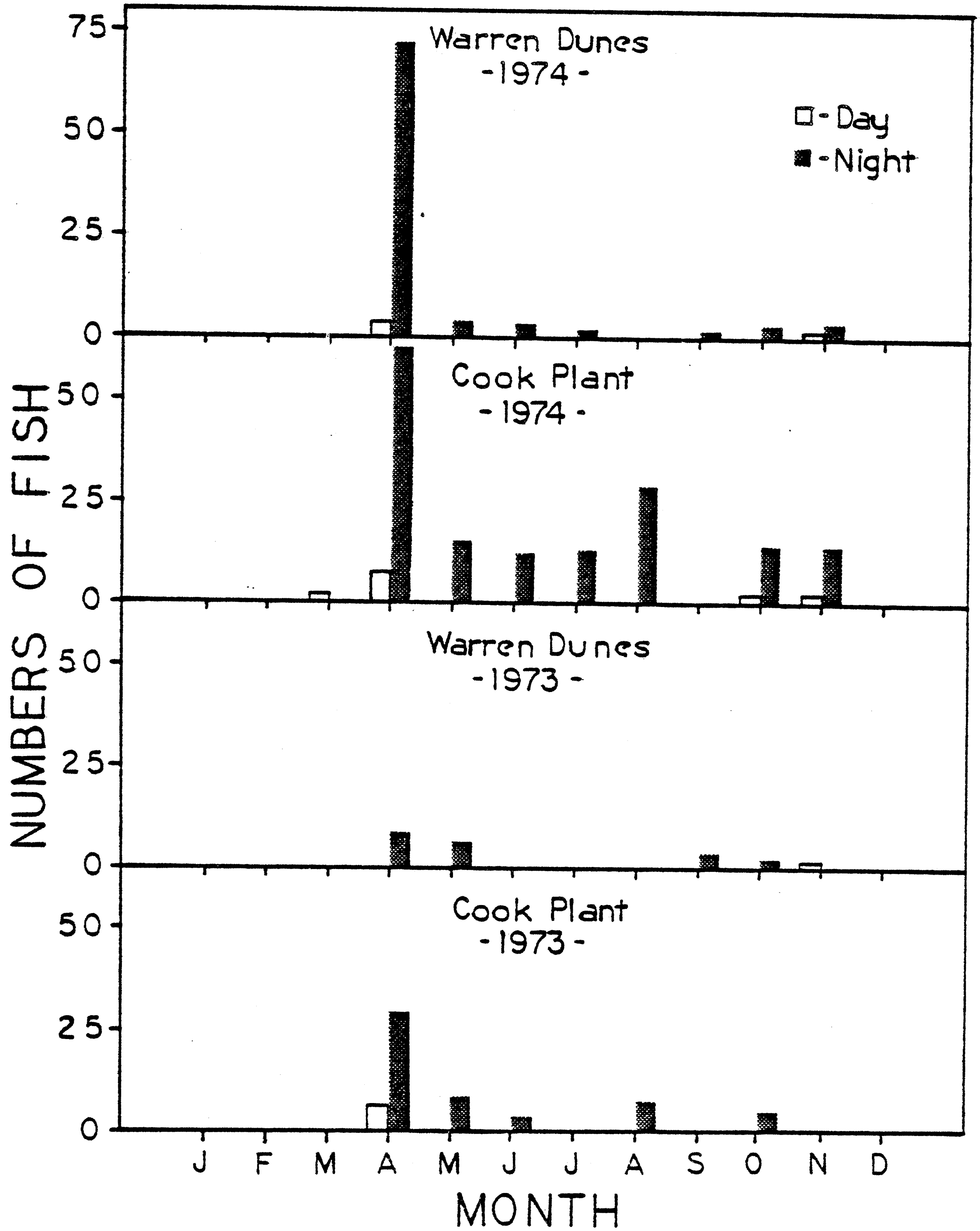

Fig. B75. Total number of slimy sculpins collected during 1973-1974 standard series sampling in the Cook Plant and Warren Dunes study areas. No sculpins were collected in standard series nets in January, February or December 1973-1974.

Table B47. Monthly gonad conditions of slimy sculpins captured during 1974 in southeastern Lake Michigan. All fish examined in a month were included.

Gonad Condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Females						
Poorly dev.			1			5	3	2			5	4
Mod. dev.	5	4	7	2	1					1	5	6
Well dev.	3	2	124	143	4						3	3
Ripe-run.				13	4							
Spent				1	27	3	63	35	16	18		
						Males						
Poorly dev.		1	1	2		2	6		8		4	3
Mod. dev.	7	2	34	27		4	2	1	1	2	16	7
Well dev.			23	31	4		1		1	7	2	2
Ripe-run.												
Spent					18	1	17	5	3	4		
						Unable to distinguish						
	1		2	1	10	9	17	19	8	5	8	5
						Immature						
			2	6	5	5	8	3	2	13	5	1

As in 1973, most sculpins in 1974 were caught in trawls (see Tables B11 and B12). Twenty-three were taken in seines; most of these during April from beach station A (N Cook). One sculpin was taken in an April night gill net.

At Warren Dunes, slightly more sculpins were collected at 9 m than at 6 m, while the reverse was true at Cook Plant stations. We have on several occasions collected large chunks of peat in the trawl. This occurred at the 6-m contour at the Cook Plant but not at Warren Dunes. The presence of a ridge of peat might provide an additional habitat somewhat more suitable than the surrounding sand, contributing to the more dense population of sculpins observed at Cook. This may be a temporary phenomenon as the material may have been dredged during pipe construction for the Lake

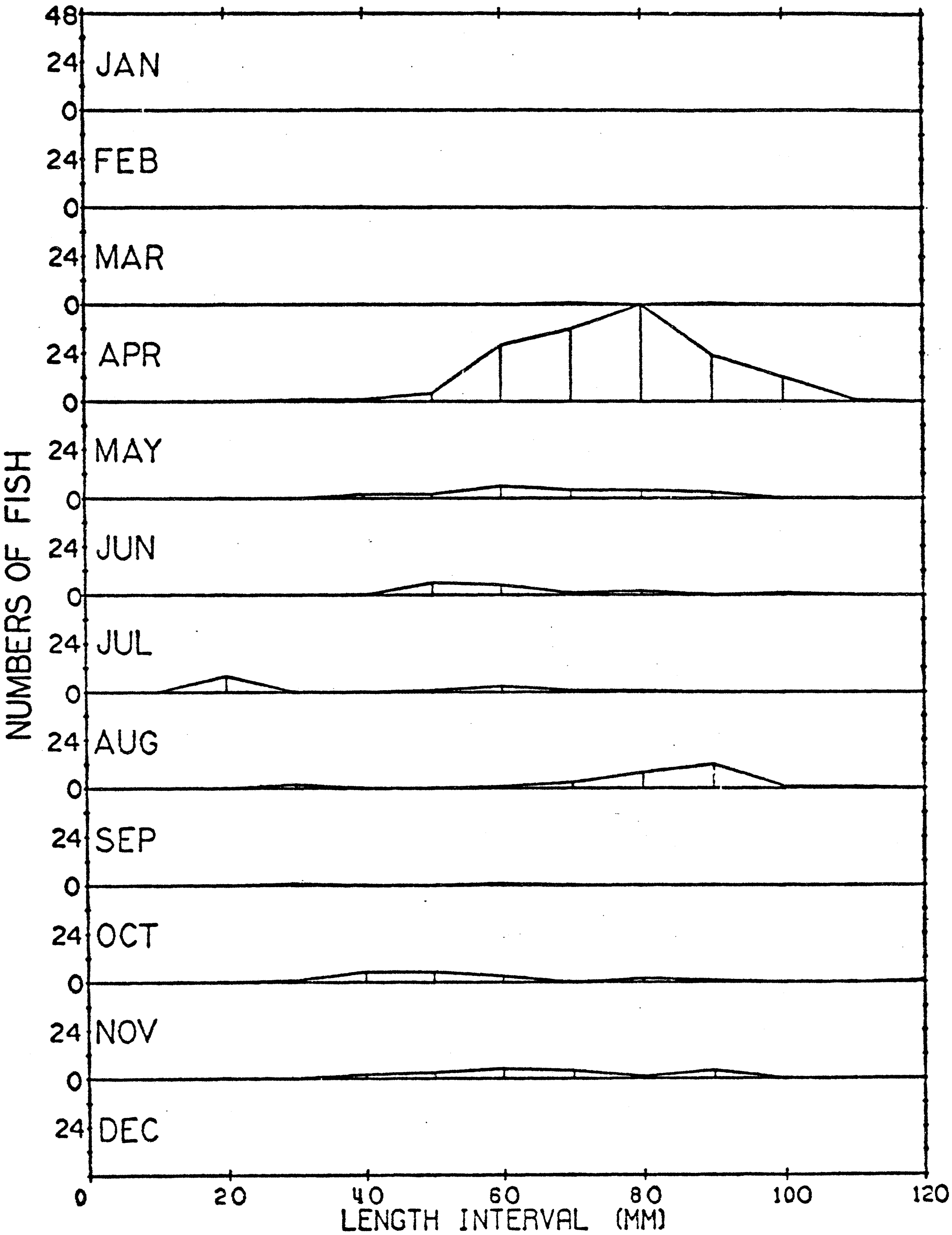

Fig. B76. Length-frequency histogram for slimy sculpins caught during 1974 in standard series sampling at Cook Plant study areas.

Table B48. Temperature-catch relationship of slimy sculpins displayed by mean catch over 2 C temperature intervals for 1973-74. All gear types were combined and the number of any gear fished at each temperature interval is shown under effort/temperature. Blanks indicate no fish were caught at that temperature.

Length Interval (mm)	Temperature Interval 1	3	5	7	9	11	13	15	17	19	21	23	25	27	Mean Catch/ Length Interval
20						0.04			0.13						0.015
30				0.02		0.01	0.03	0.06	0.02	0.03					0.018
40				0.04	0.07	0.04	0.11								0.028
50				0.07	0.13	0.07	0.07	0.08			0.11				0.053
60				0.72	0.15	0.07	0.04	0.13	0.02	0.02					0.113
70			0.03	0.81	0.16	0.04	0.01	0.03		0.05					0.106
80				1.06	0.11	0.04	0.03	0.03		0.16					0.133
90			0.03	0.54	0.03	0.04	0.03			0.21					0.081
100				0.24	0.02		0.03	0.01		0.02					0.030
110				0.02						0.02					0.003
120							0.01								0.002
Mean Catch/Interval			0.06	3.52	0.67	0.33	0.34	0.33	0.17	0.50	0.11				0.582
% of total catch/temp. interval			1.03	58.19	11.12	5.51	5.66	5.51	2.88	8.27	1.84				
Mean length of sculpin/temp. interval			80	75	64	57	59	57	26	81	50				
Effort/temp. interval	9	21	32	54	61	84	76	72	46	58	27	43	14	6	

Township water supply (see METHODS, Stations).

Nearly all sculpins (93%) were collected at night (Table B12) which might partially be explained by gear avoidance during the day. Larger night catches are also related to the nocturnal activity patterns of this species. Divers at the Cook Plant have observed that sculpins appear more active at night than during the day (Dorr 1974b, Dorr and Miller 1975), and similar observations by divers were reported in Lake Huron by Emery (1973). Evidence that sculpins may feed more intensely at night is seen in our food occurrence data. In 1973, 38% of sculpins caught during the day had food in their stomachs, while 58% of the stomachs from fish caught during the night contained food. In 1974 48% of the sculpins contained food during the day and 71% contained food at night.

In 1974 sculpins ranged in length from 15 to 118 mm (Fig. B76). Most fish fell within the range 55 to 104 mm, placing them within age-group 3-6 according to Rottiers' age and length categories (Rottiers 1965). Mean length for males we caught was 81 mm, for females, 76 mm. Slightly larger females were caught in 1974 than in 1973. Impinged fish appeared to be larger than field-caught fish in 1973, but in 1974 mean lengths for the two groups were similar, though YOY were absent from impingement collections. The largest specimen collected in 1974 was a female sculpin 133 mm in length and 20.4 g in weight.

About 10% of the sculpin population, according to our incidence data, was infected with acanthocephalan parasites. In 1975 samples, *Echinorhynchus* sp. accounted for over 90% of the acanthocephalan load, suggesting sculpin predation on amphipod intermediate hosts (Hoffman 1970). This parasite has been observed innumerable times during laboratory examination of sculpins.

Unidentified Coregonids --

During the 1974 Cook Plant study, 225 coregonids were listed as unidentified. In 1973, 148 were collected. Initially, data will be treated under the assumption that these fish were *Coregonus hoyi*. The extreme difficulty of separating the predominant bloaters, *C. hoyi*, from young *C. artedii* and other rarer cisco species will be described later in this section (see Lake Herring) and a tentative hypothesis concerning the basis of the problem will be presented. The history of decline of large populations of chubs in Lake Michigan, and subsequent changes in both bloater morphology and numbers have been well documented (Smith 1964, 1968a).

Temporal distribution of the bloater catch was extremely leptokurtic with 82% of sample fish being taken in July (Table B49). In comparing the 2 yr, several differences are immediately obvious. The general inshore presence found in summer of 1973 appears to have been reduced to a single large appearance in July of the 1974 study. Occurrence of upwellings during sampling operations in June, July and August of 1973 offers a partial explanation for this discrepancy. The substantial onshore return of YOY in October 1973 was not as pronounced the following year.

Table B49. Monthly percentage of total catch of unidentified coregonids collected in 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

	March	April	May	June	July	August	September	October
1973	0.0	0.0	1.4	17.6	40.5	25.0	1.4	14.2
1974	0.5	0.5	0.5	1.3	81.7	5.5	1.3	8.7

Temperature appears to play an important role in bathymetric movements of the bloater populations. In 1973 we associated onshore presence of bloaters with upwellings of cold hypolimnion waters (Jude, et al. 1975). Findings in 1974 lend support to this statement (see Effects of Upwellings on Fishing Distributions). Appearance of an onshore water mass in the 11-15 C range coincided well with the shallow-water presence of small bloaters, YOY in particular. The 19 *C. hoyi* taken in October 1974 were all YOY (Table B50). In all probability, these fish were attracted by the unseasonably warm inshore water temperatures (15-17 C). Noting a similar occurrence in October of 1973, it would appear that the breakup of the thermocline caused the bloaters to temporarily alter their winter migration to deeper water. YOY and juvenile bloaters appeared to be considerably more tolerant of warmer temperatures than larger adults. YOY and juveniles were taken in water temperatures ranging from 5.4 to 20.0 C, while all but one of the adults (200+ mm)were taken from a significantly colder range (6-12.5 C). These overall findings are in close agreement with the temperature range (6-20 C) for *C. hoyi* taken during 1973; however, they are somewhat higher than those found by Wells (1968).

In contrast to the 1973 results, small bloaters dominated sample catches in 1974 (Table B50). During 1974 88% of the catch was less than 200 mm in length, but in 1973 only 12% of the bloaters fell in this interval. Additionally, 76% of the 1974 sample fish were juveniles, 150 mm or less (Scott and Crossman 1973). As previously mentioned, water temperature appeared to be a major factor in the monthly length-frequency distribution. Future examination of stomach contents might also provide an explanation. Adult *C. hoyi* feed primarily on *Pontoporeia affinis*, *Mysis relicta*, copepods and small mollusks (Pritchard 1931). These organisms are generally available on or near cooler bottom waters preferred by larger fish. Young bloaters (178 mm or less) however, prefer zooplankton such as *Cyclops* or *Diaptomus* (Scott and Crossman 1973). Virtually all young *C. hoyi* caught in 1973 and 1974 were feeding when taken. One might hypothesize that temperature-related food availability controls young bloater movements more

Table B50. Length-frequency distributions of unidentified coregonids taken in monthly standard series sampling during 1974 and 1973 at Cook Plant study areas, southeastern Lake Michigan.

Midpoint of Length Interval (mm)	May	Jun	Jul	Aug	Sep	Oct	1974 Total	1973 Total
60		1				2	3	
70						6	6	3
80			3			5	8	7
90				1		2	3	13
100			11				11	3
110		2	33	2			37	
120			51				51	4
130			50	2			52	
140			16	1			17	2
150			8	1			9	
160			2				2	
170					1		1	1
180			1				1	3
190			1				1	4
200								2
210			1				1	4
220			1				1	3
230								8
240			4				4	13
250			5				5	11
260			5				5	18
270			2				2	10
280			3				3	9
290			1				1	3
300			1				1	2
310								3
			Monthly Totals					
1974	0	3	199	7	1	15	225	
1973	2	26	42	35	1	20		126

than actual thermal condition of the water. As young bloaters grow, dietary shifts generate an independence from highly variable zooplankton populations allowing more thermally-oriented patterns of movement.

The small number of mature C. hovi taken during 1974 restricts information on spawning habits. The possibility of intermittent unidentified C. artedii also limits conclusions which can be drawn. Gonads of several very large specimens (300+ mm) taken in early fall were moderately developed but not ripe (Table B51). Most likely these fish were not bloaters but lake herring, C. artedii, which spawn in November and December. The maximum sampling depth of 21 m is considerably shallower than the normally accepted bathymetric range (36-91 m) for bloater spawning activites (Scott and Crossman 1973). Several ripe fish appeared in July samples and September efforts produced a lone spent specimen (Table B51). These results agree with mid-summer spawning activity indicated by the the 1973 study. However, small fish (55-80 mm) had appeared already in June and July catches. The fish were probably yearlings, but they could have been early-hatched YOY. Wells (1966) reported February-March as the spawning period for Lake Michigan C. hovi. The 60-90-mm fish taken in October were undoubtedly YOY. Small size of these fish may point to continued spawning into summer months, an anomaly which was discussed by Jobes (1949).

The overall sex ratio of 18 males to 33 females was less than that found in 1973 (59 males to 83 females). The percentages of males (28.4%) and females (71.6%) were very similar to figures which Brown (1970) calculated for sample data taken during the late 1920's, indicating a possible trend away from the lopsided sex ratio (94 to 97% females from 1963 to 1969) which appeared during the last 20 yr. A breakdown of our entire bloater catch shows 167 immatures (76.5%), 33 females (15.2%), and 18 males (8.3%).

In general, adult fish were taken by gill nets set at deeper stations (9 m, 21 m), while the bulk of small bloaters (170 mm or less) were taken by trawling. Two small fish were seined immediately south of the Cook Plant in August 1974 during an upwelling. Seventy-nine unidentified coregonids were taken at 6-m stations, the majority of them in trawls. Finally, it should be noted that all conclusions must be qualified by the fact that existing sampling efforts for the Cook Plant study are reaching only the inshore fringes of the deepwater bloater concentration which may or may not be representative of the population itself.

Coho Salmon --

We caught 153 coho salmon in standard series fishing during 1974 (Table B9), most in May (71) followed by August (26) and November (25). None were caught in January, September, October or December. In comparison, 32 coho were captured in standard series fishing during 1973 (Table B6). All 1974 fish were caught in gill nets (103) and seines (50); during the night 106 fish were captured; whereas, during the day 47 were taken. In 1973, 23 coho were caught at night and nine during the day. The data indicate a pattern of predominantly nocturnal activity for this species. There appeared to be

Table B51. Monthly gonad conditions of unidentified coregonids as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1974 in southeastern Lake Michigan. All fish examined in a month were included.

Gonad Condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
					Females			
Poorly dev.					13		1	1
Mod. dev.					14	2	1	
Well dev.								
Ripe-running								
Spent					1		1	
					Males			
Poorly dev.				1	7			
Mod. dev.					8	1		1
Well dev.					1			
Ripe-running								
Spent								
					Immatures			
	1	1	1	2	106	8		17
					Unable to distinguish			
					4			

little difference between numbers caught at the Cook Plant and Warren Dunes.

In 1974, 35 fish were captured in supplementary fishing; 29 (410-618 mm) in gill nets, primarily those set at night in May and June, and six (133-174 mm) in a day seine in June. One additional fish (235 mm) was impinged on the traveling screens in August 1974. Total 1974 unadjusted catch of coho was 189. Range in size of all fish captured was 89-645 mm (6.8-3100 g) with the 100-200-mm size group most abundant. The length-frequency histogram (Fig. B77) for coho shows a distinct bimodal distribution. One peak consists primarily of small fish 75-175 mm taken in seines, the other adult fish 375-575 mm taken in gill nets.

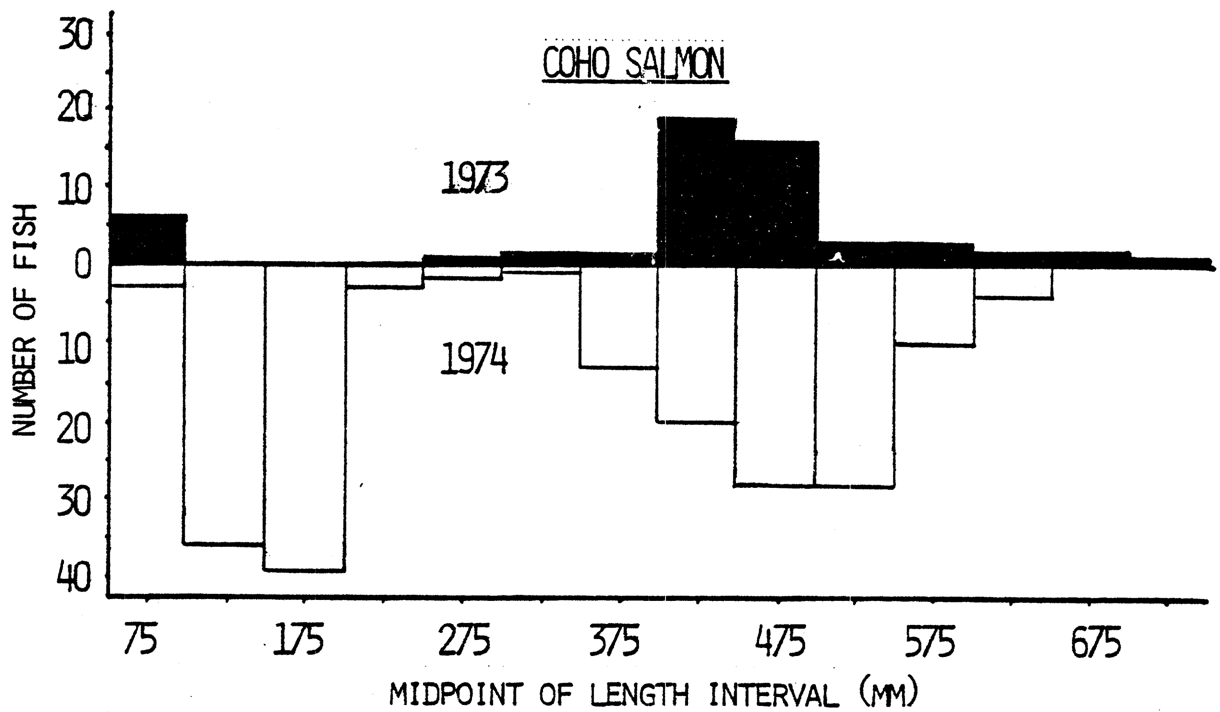

Fig. B77. Length-frequency histogram for coho salmon caught during 1973-1974 standard series and supplementary fishing activities at Cook Plant study areas, southeastern Lake Michigan.

Fifty coho were seined, primarily in May (31) and June (13). These were small (109-175 mm, 14.5-31.2 g), immature fish, probably from 1974 spring plantings by Michigan and Indiana Departments of Natural Resources. During 1973 we seined only nine coho (73-95 mm), none in the 100-200-mm size range. However, there were no significant plantings of this fish in southeastern Lake Michigan during 1973. These data suggest yearling coho inhabit the beach zone from the time of planting (April) until June when they move offshore, perhaps following the retreating thermocline. During August 1974, 26 fish (170-282 mm, mean length 188 mm) were captured in gill nets set at night at 9 m during a slight upwelling. Undoubtedly, these were again fish from the spring planting, now moving inshore following the advancing thermocline.

Gillnetted fish in 1974 ranged from 170 to 645 mm (49.3-3100 g.). Highest catch was in May (40 adults) followed by August (26 immature) and November (25 adults). Gill net catches of adult fish (400 mm) reflected the seasonal pattern of movement typical for this species; inshore activity from early spring through early summer, an offshore movement in summer following the thermocline, a return to inshore waters with the advent of fall spawning activities and the disintegrating thermocline, and an offshore movement during early winter as water temperatures decreased. A similar seasonal pattern was observed in a small lake in Wisconsin (Engel and Magnuson 1971). We have never captured coho in trawls.

Gonad data (Table B52) showed that male and female fish had a predominance of spent, poorly and moderately-developed gonads between March

Table B52. Monthly gonad conditions of coho salmon as determined by inspection and classification of development of ovaries and testes. Fish were captured during 1973 and 1974 in southeastern Lake Michigan. All fish examined in a month were included except poorly received specimens.

Gonad Condition	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.	2	6	2	32	3		1		1	14	1
Mod. dev.		6	5	5							
Well dev.								1			
Ripe-running											
Spent		1		9							
					Males						
Poorly dev.		5		19	6						
Mod. dev.			1					2			
Well dev.								4			
Ripe-running											
Spent				1							
					Immature						
		2	5	36	18	2	26		1		
					Unable to distinguish						
	1	4		9					2	11	

and June, indirectly substantiating fall spawning. Fall spawning movements of coho are directed toward the mouths of rivers and major tributarities (Scott and Crossman 1973). The Cook Plant is not close (the St. Joseph River is within 16 km) to any rivers or major streams, which may account for the relatively low fall catch of adults with ripe gonads. Future data should continue to document the fall spawning habits of this species. Immature fish were captured March-June, August and October with largest catches during May, June and August. We were unable to determine the gonad condition of 27 fish; however, they were probably spent or specimens with poorly-developed gonads taken shortly after spawning or during the spring.

Based on an average planting length in April of 120-130 mm (Peck 1974 cites 100-150 mm for some 1968-1969 plantings in Lake Michigan) for yearling coho (A. Lamsa, personal communication, Great Lakes Fishery Commission, Ann Arbor, Mich.), the lower size limit (89 mm) reflected in our data would suggest natural recruitment of coho may have occurred in our study area during 1974. An alternate possibility is that fingerling chinook (89-100 mm), originating from fall plantings and/or natural recruitment, may have been mistakenly identified as coho.

Coho were captured over a wide range of water temperatures (Fig. B78) but catch showed a normal distribution with a strong peak at 11 C. Fish 70-90 mm were caught at water temperatures near 23 C. Yearling fish 100-170 mm were captured at temperatures between 11-17 C while longer fish were taken primarily when water temperatures were 11 C or less.

White Sucker --

In 1973, 199 white suckers were caught with standard series nets, but in 1974 only 126 fish were caught (see Tables B6 and B9). An examination of monthly catches shows most of the 1974 decreased catch occurred during August, September and October. Although it is possible that the local population decreased in 1974, we suspect that distribution changes caused by water temperature differences occurred during August and September. Causes for the decreased October catch are unknown.

While monthly average temperatures for August and October were considerably lower in 1974 compared with 1973, but similar in September (see Figure B6), there were other dissimilarities in temperature at the time of sampling during each month. During August and September, average temperatures at the time gill nets were set were considerably colder in 1973 (Table B53). Upwellings caused the decreased temperatures in 1973. We believe that cold water from upwellings "forced" white suckers from deeper water into the vicinity of our gill net stations during 1973 and caused high catches. Emery (1970) observed that white suckers moved shoreward and stayed close to the shoreline in warm water (20.2 C) when an internal seiche in Lake Huron brought cold water (7.0 C) inshore. In our study areas during August and September 1974, temperatures when gill nets were set were higher than those found in 1973 and suckers were spatially distributed over a greater area (probably into deeper water) and therefore catches were low at

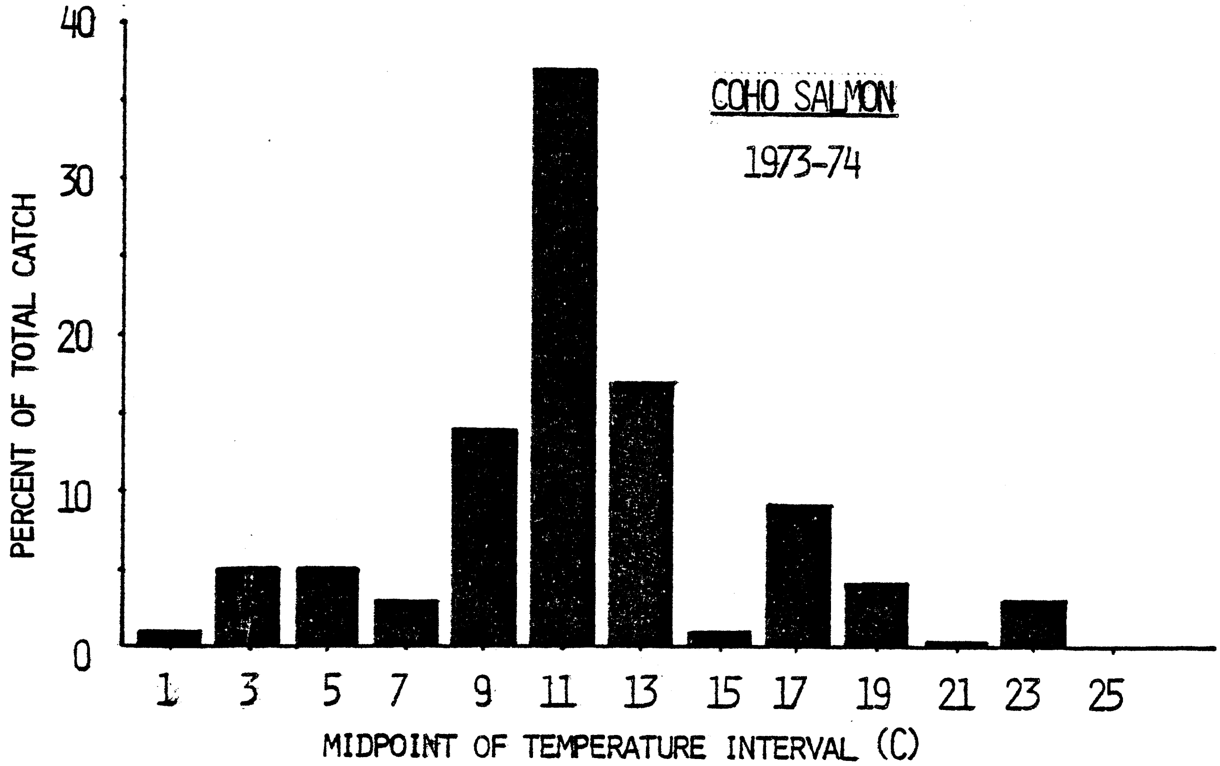

Fig. B78. Temperature-catch relationships of coho salmon as shown by the percentage of the total catch occurring in each 2 C interval during 1973-1974. All gear catches were combined. (N = 57 for 1973 and 189 for 1974).

Table B53. Average water temperatures and standard error at the time standard series gill nets were set during August, September and October 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan. Each value is the average bottom temperature (C) at the four gill net stations (C,D,G and H).

	August		September		October	
	1973	1974	1973	1974	1973	1974
Day	13.0±1.7	20.4±0.7	12.1±0.3	18.2±0.1	12.9±0.8	13.4±0.2
Night	10.1±1.3	16.7±1.5	14.5±1.5	17.9±0.2	13.8±0.1	13.4±0.2

gill net stations. Water temperatures during the October sampling period for both years were similar, but catches were lower in 1974 for unknown reasons.

Increased fishing effort during January, November and December 1974 was reflected in increased white sucker catches during these months. Only one sucker was caught during January, February, November and December of 1973, undoubtedly because of the few nets fished. Catches during cold months for both years indicate these fish were present inshore throughout the year.

During 1973 and 1974, few suckers were caught in April. Gonad development showed that spawning occurred in March, April and May 1973. Most spawning probably occurred in April. We concluded that spawning occurred outside the study area probably in rivers and streams, and therefore April catches were low. Gonad development in 1974 also indicated that spawning occurred in March, April and May (Table B54). Spent fish were not caught until April; thereafter numbers of spent fish caught increased

Table B54. Monthly gonad conditions of white suckers as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1974 in southeastern Lake Michigan. All fish examined in a month were included.

Gonad Condition	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.			1			2	1		1		1
Mod. dev.	1	1			7	2	10	9	2		2
Well dev.	1	4	1	5	3				3	1	5
Ripe-run.											
Spent			2	11	6	23	1		1		
					Males						
Poorly dev.		1		3	3	3			1	2	
Mod. dev.		2			4	1	2	6	6		1
Well dev.									1	2	1
Ripe-run.											
Spent			1	3	1	5					
					Immature						
			1			4	1	1			
					Unable to distinguish						
				2				1			

into summer. Low numbers caught in April 1974 again indicated that spawning probably occurred outside the study area, and that most spawning occurred during April.

White suckers were predominantly caught by gillnetting during both years (79% and 90% of the standard series white sucker catch in 1973 and 1974 respectively). More suckers were gillnetted at Warren Dunes than at Cook during both years (Table B55). The exact cause for this spatial difference is unknown, but a small stream enters the lake at Warren Dunes (see Fig. B1) and may attract white suckers to this area. We have observed YOY white suckers in this stream.

Table B55. Numbers of white suckers caught by standard series gill nets in 1973 and 1974 at Cook Plant study stations, southeastern Lake Michigan.

	1973 Stations					1974 Stations				
	Cook		Warren Dunes			Cook		Warren Dunes		
	C-6 m	D-9 m	G-6 m	H-9 m	Total	C-6 m	D-9 m	G-6 m	H-9 m	Total
Day	8	4	22	15	49	1	3	9	10	23
Night	14	8	60	29	108	27	5	38	22	92
Total	22	12	82	41		28	8	47	31	

In general, more suckers were gillnetted at 6-m stations (C and G) than at 9-m stations (Table B55). More suckers were caught at night than during the day in both years. These spatial and temporal differences were caused by behavior patterns of white suckers. Emery (1973) found white suckers in Greenleaf Lake, Ontario to be more active at night at 0.5-10-m depths. He also found that abundance in shallow water increased at night. Spoor and Schloemer (1939) found white suckers in Muskellunge Lake, Wisconsin during July moved inshore (depths less than 6 m) in the evening (1900-2000) and offshore (6-8 m) in the morning (0300-0500). This inshore-offshore movement also occurred in Lake Michigan at the study areas in 1973 and 1974. The fish were at 6-9 m during the day, then moved inshore (6 m and less) at dusk and offshore in the morning. High night catches at 6-m stations reflected this movement. We suspect that day catches at 6-m stations would probably be less if day gill net sets were removed earlier. Day sets probably sampled some suckers which moved at dusk. Day sets were usually removed

before darkness, but in some sampling periods late lifts occurred after sunset.

One series of short period gill net sets revealed information on sucker movements. During July 1973 a diel series of gill net sets were performed to analyze yellow perch movements (see Yellow Perch). Nets were set at stations C (6 m) and D (9 m) for the following time periods: 1415-1615, 1615-1815, 1815-1945, 2000-2230, 2300-0415 and 0515-1530. At 6 m one sucker was caught between 2000-2230 and four between 0515-1530. At 9 m one sucker was caught between 2000-2230 and two suckers were caught between 2300-0415. These catches demonstrated that movements of white suckers in our area were similar to those found by Spoor and Schloemer (1939). Suckers moved into depths of less than 6 m between 2000-2230 and began moving out between 0515-1530 (probably at the earlier part of the time period). The two suckers caught at station D between 2300-0415 do not quite fit the pattern. They may have been part of the inshore or the offshore movement. We suspect they were caught later in the period and were moving offshore.

These inshore-offshore movements are probably responsible for the large night catches observed. Most day gill net sets would probably be pulled just before or during the inshore movement. Most night sets would collect fish from part of the inshore and most of the offshore movements.

While gill net catches accounted for the majority of white suckers caught, some were caught by trawling and seining. In 1973 11 fish were caught by standard series trawling and in 1974 six fish were caught. Undoubtedly most suckers can effectively avoid the trawl and therefore trawl catches underestimate the abundance of suckers. Some white suckers were caught by standard series seining during both years (31 in 1973 and 7 in 1974). Seine catches, like trawl and gill net catches, decreased during 1974. Seine catches demonstrated that white suckers utilized the shallowest depths of the lake. Their presence may be due to feeding activities. While gill net catches revealed increased abundance and activity nocturnally, day seine catches of suckers (nine fish) suggest some diurnal activity in the beach zone, although most (29) fish were seined at night.

The majority of white suckers caught by total fishing efforts in 1974 were adults (Table B56). In 1974, 83% were 395-594 mm while in 1973, 63% were in this size range. This difference was caused by lower catches of smaller fish in 1974. The conditions responsible for this decrease are unknown. We can postulate that generally warmer temperatures in 1973 (see Fig. B6) caused increased utilization of the study areas by suckers. It is also possible that population structures were different between years due to strong year classes, but all size groups were caught in lower numbers in 1974. This again points to a distribution change due to temperature variation rather than a population change.

Two small suckers caught in July were both 35 mm (Table B56). These YOY apparently stay in shallow water, because both were seined. It is also possible that some fish caught during both years in the 45-94-mm size group

Table B56. Length-frequency distributions of all white suckers caught during 1974 at Cook Plant study areas. Catches from all gear are pooled.

Length Interval (mm)	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
0–44						2						2
45–94						1	1					2
95–144								1				1
245–294						1			1			2
295–344		1		1			1	1		1	1	6
345–394			2	3	1	3			2	1		12
395–444	1	1	2	8	10	7	1	3	4		2	39
445–494		3		6	7	8	3	6	3	1	3	40
495–544		4	3	2	3	11	4	4	1	2	2	36
545–594	1	1	1	4	2	9	4	2	4		2	30
595–644					1	2	1					4
Totals	2	10	8	24	24	44	15	17	15	5	10	174

were YOY. Beamish (1973) found white suckers from George Lake, Ontario to be 75-175 mm (fork length) at 1-yr old. Although the small size of the two YOY suckers caught in July 1974 may indicate these fish were spawned in the lake, sucker fry spawned in streams from lake-run adults do not remain in streams for very long. Geen et al. (1966) found peak fry migration downstream occurred 1 mo after spawning in a tributary to Sixteenmile Lake, British Columbia. Whether the two YOY we caught were spawned in the lake or in tributaries remains unresolved.

In general smallest fish were caught by seining, while very few small fish were caught in gill nets (Table B57). Evidently smaller fish do not range into the 6- and 9-m depths, but stay in shallower water. Very few small fish were caught (especially in the 145-244-mm size range) during both years. We do not fish extensively between 2 and 6 m. Gill nets were set

occasionally at station A in 1.5-3-m depths, perpendicular to shore, but no small suckers were caught (Table B57). If smaller fish commonly reside at these depths especially between 3 and 6 m, we undoubtedly are underestimating their numbers in the study areas.

Table B57. Length-frequency distributions of all white suckers caught during 1974 with gill nets, seines and trawls at eight stations in Cook Plant study areas.

Length interval (mm)	Fishing gear			Station							
	gill net	trawl	seine	A[1]	B	F	C	D	G	H	E
0-44			2			2					
45-94			2		2						
95-144			1		1						
245-294	1	1		3					1	1	
295-344	5		1	5		1		1		1	
345-394	11		1	9	1			1	3	2	
395-444	37	2		6			10	3	10	7	
445-494	38	2		14			5	3	19	7	
495-544	36			5			5		9	7	1
545-595	29	1					9	2	6	7	1
595-644	4						2		2		
Totals	161	6	7	42	4	3	31	10	50	32	2

[1]The only white suckers caught at station A were gillnetted.

Two fish were caught at 21 m (station E) in 1974 (Table B57). In 1973 two fish were also caught at 21 m (Table B38 page 184 in Jude et al. 1975 indicates six fish, but this is an error - four of these fish were caught at 15-m - station 5). The depth range limit of white suckers in the study area was 21 m, because of the very low catches there. During the summer in Horsetooth Reservoir, Colorado, the deepest depth from which white suckers were captured was 22 m (Horak and Tanner 1964). Scott and Crossman (1973) stated that white suckers have been recorded below 46 m in Great Slave Lake, Canada.

More females than males were caught during 1973 and 1974. There was no distinctive difference between the 2 yr in the female-male ratio (62% females in 1973 and 69% in 1974). Scott and Crossman (1973) stated that females achieve larger sizes than males. Our data also indicated this size-sex relationship. Of the fish 500+ mm in length, 82% (46 fish) were females in 1973 and 90% (54 fish) in 1974. The largest fish caught in 1973 was a 623-mm (2900 g) female. White suckers in the study area are reaching maximum sizes for this species; McPhail and Lindsey (1970) gave maximum size as 635 mm (3200 g).

Two fish caught in 1973 and three in 1974 had lamprey scars. Incidence (based on all fish caught) was 1.7% in 1973 and 0.5% in 1974. Lamprey scarring of white suckers has been reported by Hall and Elliott (1954) and Coble (1967) in Lake Huron. Hall and Elliott (1954) found that the percentage of fish bearing scars increased as size of the suckers increased. The fish we collected with scars were large in size (470, 506, 545, 563 and 578 mm).

During 1974 a neoplastic lesion was noted on 12 white suckers. It was only found on the head and usually on the lips of the fish. These lesions ranged in size from 10 to 50 mm in diameter. The fish were large in size averaging 533 mm (range 468-598 mm). Nine were females and three were males, six were caught off Warren Dunes and six off Cook. The cause and histological nature of these growths were undetermined.

White suckers were caught over a wide temperature range (0-25.9 C) during 1973 and 1974 (Fig. B79). This wide range demonstrated that fish were present in the study area thoughout the year. It further indicated that white suckers probably did not move extensively to find discrete water temperatures. From laboratory experiments, Cherry et al. (1974) found that very small white suckers did not show thermal responsiveness for temperature conditions between 6 and 30 C.

A high percentage (45%) of the total catch was captured in the 12-17.9 C range (Fig. B79) indicating that suckers probably have some preference for the upper end of this temperature range. Horak and Tanner (1964) gillnetted most white suckers in water temperatures from 16-21 C during the summer in Horsetooth Reservoir, Colorado. Although we caught only 25 small (<200 mm) white suckers, these fish were captured in warmer water (mean temperature 22 C) than larger fish (mean temperature 13 C). Apparently larger fish preferred colder temperatures than juveniles. This size-temperature relationship was also noted for alewives, spottail shiners, yellow perch and johnny darters.

Lake Trout --

During 1974, 209 lake trout were captured in the study area, 125 in standard series nets and 84 in supplementary netting operations. Gill nets caught 204 fish, trawls caught four and beach seines one.

A seasonal peak in numbers of lake trout caught in 1974 occurred during November (Table B58); peak numbers captured in 1973 occurred during September, October and November. Observed seasonal abundance correlated well with known onshore spawning movements during fall months. Examination of data (Table B58) suggested several general patterns of lake trout movement. Activity was higher at night; 91% of the fish in 1974 standard series catches were taken at night. Eighty-three percent of the fish in 1973 standard series catches were caught at night. Data from 1974 (Tables B59 and B60), 1973 (Jude et al. 1975) and supplementary catches supported indications of heightened onshore nocturnal activity.

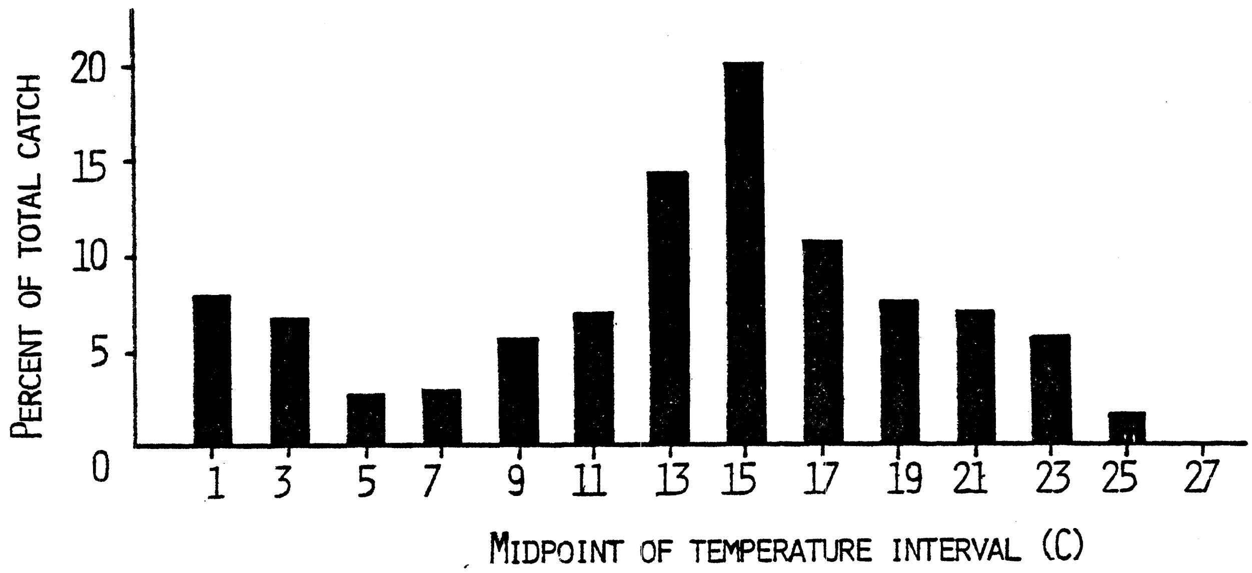

Fig. B79. Percentage of the combined total standard series catch of white suckers for 1973 and 1974 collected from different water temperatures at Cook Plant study areas, southeastern Lake Michigan.

Lake trout were captured more frequently at 6-m than 9-m stations during 1974 as well as during 1973. Supplementary netting during 1973-1974 reflected both inshore abundance and alongshore movement of lake trout, particularly during the fall. Seasonal inshore abundance, nocturnal activity and alongshore movement patterns of lake trout may be primarily attributed to fall spawning activity which is known to take place after dark (Scott and Crossman 1973). It is unlikely that observed activity could be attributed to feeding behavior as approximately 88% of the fish caught during 1973-1974 from September through November had empty stomachs. Catches at 21 m (Table B60) revealed the presence of lake trout offshore during periods (January-April and July-September) when no fish were netted at 6- or 9-m stations (Table B58).

Table B58. Comparison of 1974 monthly day-night catches of lake trout from standard series gill nets set in Cook Plant study areas, southeastern Lake Michigan. Numbers caught were adjusted to catch per 12 h.

Station	Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cook Plant	DAY	-	-	0	0	1	0	0	0	0	1	1	0
6 m - Sta. C	NIGHT	0	-	0	0	4	2	0	0	0	9	41	0
Cook Plant	DAY	-	-	0	0	3	0	0	0	0	1	0	0
9 m - Sta. D	NIGHT	0	-	0	0	3	2	0	0	0	0	23	0
Warren Dunes	DAY	-	-	0	0	0	0	0	0	0	0	1	0
6 m - Sta. G	NIGHT	-	-	0	0	3	5	0	0	0	1	15	0
Warren Dunes	DAY	-	-	0	0	2	0	0	0	0	0	0	0
9 m - Sta. H	NIGHT	-	-	0	0	0	0	0	0	0	0	2	0

Examination of gonads (Table B61) showed an increase in ripeness of ovaries and testes beginning in September and peaking during October-November. Spent fish first appeared during September but peaked during November. Inferred October-November peak spawning period agreed well with accepted classification of lake trout as fall spawners.

Several reasons for the apparent lack of natural reproduction of Lake Michigan lake trout have been advanced. Rybicki and Keller (1976) suggested that planted lake trout fail to find traditional offshore spawning reefs, contaminants may reduce viability of eggs and fry and fish predation on lake trout eggs may be heavy. In addition to the previous reasons, Gibson (1976) suggested that siltation and subsequent suffocation of eggs may be occurring.

Rybicki and Keller (1976) reported large concentrations of spawning lake trout were found at inshore reefs near Charlevoix and northern Green Bay, especially in areas where they were planted. Planted fish and fish hatched from fish eggs planted on offshore reefs have not yet reached sexual maturity. There is evidence that salmonids often return to spawn near the location where they were planted; therefore suitability of planting locations as potential future spawning grounds may be critical to successful spawning of planted lake trout. Spawning success on certain reefs (such as the extensive Sheboygan-Milwaukee Reef complex) may be limited to strains (Green Lake strain in this case) of fish which historically spawned on these mid-lake deep-water reefs (Lake Michigan Committee 1976).

Fish species identified as predacious upon lake trout eggs include: lake trout and whitefish (Rybicki and Keller 1976), burbot (Lake Michigan

Table B59. Number of fish caught during 1974 at supplementary station A in gill nets set perpendicular to shore. D = day; N = night. See Table B5 for definitions of species abbreviations.

	STATION A - 1 m N. Cook																				
	Jan 28 N	Jan 28 N	Mar 6 D	Mar 15 D	Apr 10 D	Apr 18 D	Apr 19 D	May 13 D	May 15 N	Jun 12 N	Jun 14 D	Jul 10 D	Jul 11 N	Aug 20 N	Aug 22 D	Sep 9 N	Sep 11 D	Oct 8 N	Oct 10 D	Nov 26 N	Dec 20 D
Species																					
SP			3	1			2	64	188	291		1	89	2		13		13		24	1
AL				239	153		197	183	278	154	16	76	1337	50		9		3	1		
SM								4	1				1			2		8			
YP					3				2	1	62	207	122	27		59				1	
TP								2	3	1			1			3		1			
WS			3	4		1	4	2	6	2		2	13	2		1		1	1		
LS		1		1		2			1	1			1								
LT				1		1	4	5	4	1								41	5		
CH																2		2			
RT	6	6		2	3													1	1	7	1
CP				1	3	1		3	2		16	3	3	2	1	5		3			
CM		3		4				2	9							1			2		
BT		1		3	3	3	6	9	3		2					1			2		
SS																					
CC																2					
LG													1								
NP				1	3			2	1				1								
GS														1		12		4			
XC																					
LW																					
BR	1	1																			
QL											4				4						
SB									1												
RB			3																		

Table B60. Number of fish caught during 1974 in gill nets fished at supplementary station E which is located in front of the Cook Plant in 21 m of water. D = day; N = night. See Table B5 for definitions of species abbreviations.

STATION E - 21 m Cook

	Jan 3 N	Jan 3 N	Mar 15 D	Apr 19 D	May 20 N	Jul 10 N	Aug 21 N	Sep 10 N	Oct 23 N	Nov 29 D	Dec 20 D	Dec 24 N
Species												
SP			1	12					3	5		
AL			4	17	39		15	2	18	2		
SM	2	1	5	6	8	2	6	10	8	8	9	
YP	5	4	4	6	2				8	22	5	
TP	2	1			1	1			9			
WS												2
LS	6	23	1		2					10	4	2
LT		6	3	2	3	3	3	3		1		
CH												
RT												
CP												
CM									1			
BT												
SS					2							
CC												
LG		1										
NP												
GS												
XC					1	2	3	2	3			
LW		1							2			
BR		1										
QL												
SB												
RB												

Table B61. Monthly gonad conditions of lake trout as determined by inspection and classification of state of development of ovaries and testes. Fish were captured during 1973-1974 in southeastern Lake Michigan. All fish examined in a month were included.

Gonad Condition	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov	
	74	73	74	73	74	73	74	73	74	73	74	73	74	73	74	73	74	73	74	73	74	73
Females																						
Poorly dev.							1		12			1	1					1				
Mod. dev.									2	1	10			6		13	1	6	2	8	2	
Well dev.				1				1										21	21	31	2	1
Ripe-running																			1	2	14	6
Spent	2				1	2	2	1		1											5	
Males																						
Poorly dev.					2			3	9							1						
Mod. dev.											1			1	3	7	2	19	11	35	3	
Well dev.									1	1								9	23	15	8	4
Ripe-running																					42	4
Spent	1					1	1											1		3	10	1
Immature																						
	3				2		1		3	1		4	1			1		1		2		
Unable to distinguish																						
									2				1									

Committee 1976, Scott and Crossman 1973), round whitefish (Loftus 1958, Armstrong, 1973), brown bullhead (Scott and Crossman 1973) and yellow perch (Gibson 1976). Although documentation was not found, sculpins might also be suspected to prey upon lake trout eggs, since we have on several occasions found impinged sculpins in November through December with stomachs full of what we believe to be lake trout eggs. Undoubtedly eggs were obtained from riprap areas around the intakes where sculpins are known to reside (Dorr and Miller 1975) and where some suspected lake trout spawning occurred.

Among the list of contaminants which may adversely affect survival of lake trout eggs and fry are: chlorinated hydrocarbon pesticides such as DDT and dieldrin and industrial wastes such as polychlorinated biphenyls (Gibson 1976). Siltation on lake trout eggs has been observed by Michigan Department of Natural Resources' biologists (Rybicki and Keller 1976) and may result in suffocation of eggs (Gibson 1976).

During 9-10 November 1975, an intense storm passed through the Great Lakes region generating wave heights in excess of 5 m along the Cook Plant shoreline. On 11 November, an estimated 100,000 eggs were observed along the surge line covering an area 0.5 m wide by 1200 m in length. Thousands of eggs were also present in the water and farther onshore but numbers were not estimated.

On 12 November 1975, a few lake trout eggs were observed along the beach near Charlevoix, Michigan; this beach is adjacent to known spawning grounds approximately 1.6 km offshore (T. Stauffer, personal communication, Marquette Fisheries Research Station, Michigan Department of Natural Resources). In the same communication, Stauffer also reported that eggs planted during December, 1974 on an offshore reef (Irishman's Grounds) near Charlevoix at a depth of 11 m in 54.5-kg rubble-filled containers, were subjected to severe wave action; 12 containers were planted, all but one were lost. Clady and Hutchinson (1975) cite wind-induced dislodgement and beaching of eggs spawned by yellow perch in Oneida Lake, New York, along with similar occurrences noted by other investigators.

Scott and Crossman (1973) reported 400-1200 eggs per pound of female lake trout may be deposited during spawning. Our data show a mean weight of 3.8 kg for a typical, well-developed and ripe-running female lake trout in our study area. Therefore, eggs observed (on 11 November 1975 near the Cook Plant) along the surge line alone would constitute the entire spawn of 10-30 fish. Assuming not all eggs deposited would be washed ashore or observed and numbers of eggs in the lake and farther onshore were not included in the surge line estimate, total numbers of observed eggs may have represented spawning efforts of many times more than 10-30 fish.

Samples of the eggs were collected, diameters of eggs measured and species identity confirmed. Approximately 200 eggs were examined; none showed outward signs of fertilization or embryonic development. Inshore water temperatures at time of collection ranged from 10.5-11.5 C, well within spawning-temperature preferences of lake trout reported by Scott and

Crossman (1973).

Current-speed measurements (Indiana and Michigan Power Company 1977) indicated that under certain conditions of strength, direction and duration, current, along with wind and wave action, could provide long distance (50 km or more) transport for lake trout eggs. However, since riprap presents a substrate similar to that described as suitable for lake trout spawning, the possibilty that some of the eggs observed washed ashore at Cook Plant may have been deposited locally and subsequently dislodged by the unusually heavy wave action, may not be ruled out. Unfortunately, entrainment pumping and diving observations were not conducted during the immediate time period and cannot confirm presence of eggs in the Cook Plant riprap area. Our observations of fish predation upon lake trout eggs provide additional but inconclusive evidence supporting nearby spawning of lake trout. As previously noted, sculpins have been impinged at the Cook Plant in November and December with stomachs full of suspected lake trout eggs. On 8 November 1976, a juvenile (229 mm) lake trout was trawled at 6 m (station R-N Cook); its stomach contained 53 recently-ingested unfertilized lake trout eggs. Three loose eggs also appeared in the same trawl catch but may have been disgorged by the juvenile.

Size of lake trout captured ranged from 112 mm (7.6 g) to 817 mm (5400 g). Fish caught in gill nets ranged from 274 mm (178.7 g) to 817 mm (5400 g), in trawls from 139 mm (17.2 g) to 725 mm (3400 g). One fish (112 mm, 7.6 g) was seined.

Length-frequencies of lake trout captured during 1973 and 1974 (Fig. B80) point out the preponderance of fish 600-800 mm in length. Numbers of fish captured that were 600-700 and 750-800 mm decreased during 1974 compared to 1973 catches, while numbers of fish captured that were 700-750 mm increased. Fish less than 300 mm were captured primarily in trawls and seines, although two adult fish (592 and 725 mm) were caught in trawls during 1974.

Table B62 presents length distributions of year classes of lake trout caught during 1973 and 1974. Data were separated by age at date of capture; back-calculated age-class growth was not estimated. Ages of fish were determined by analysis of fin clips and planting records; age analysis of fish scales was not performed. Some subjective decisions were made when assigning certain fish to a given age, primarily when similar fin clips were used within the same 2-3-yr period, permitting overlap in size of similarly marked fish from different ages.

The literature (Scott and Crossman 1973, Scott 1973, Rybicki and Keller 1976) indicates that lake trout become sexually mature between ages 5 and 7. Ninety-three percent of the fish we captured were age 5 or older; few juvenile fish were taken. Smaller fish were probably less vulnerable to our netting gear and did not concentrate inshore with spawning adults during the fall, when we capture the majority of our lake trout.

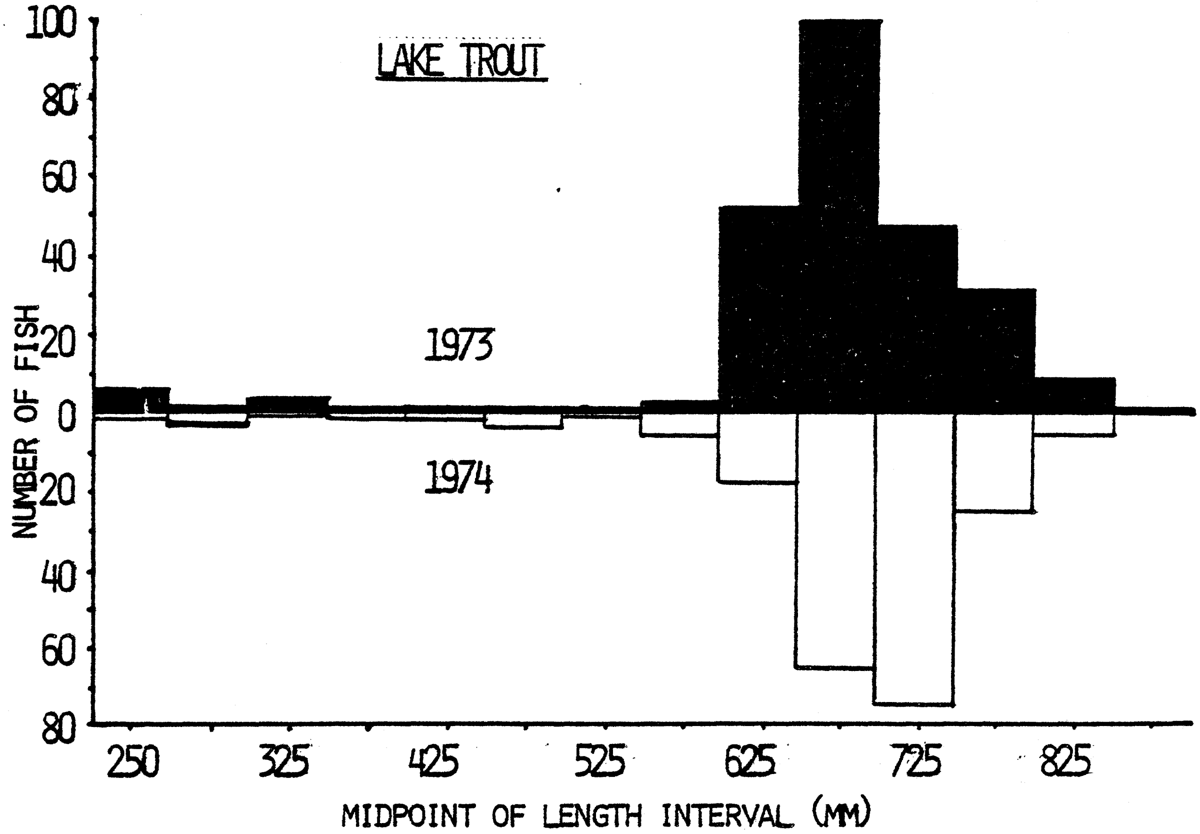

Fig. B80. Length-frequency histogram for lake trout caught during standard series and supplemental fishing activities in 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

Age 5 and 6 fish composed nearly 71% of the 1973 catch. No fish older than age-class 8 were taken indicating that by 1973, 1964 year class fish were rare or non-existent in our study area. However, the 1964 year class was stocked exclusively in the northern basin of Lake Michigan. The 1970 year class of lake trout did not appear in our 1973 catch and only two were taken in our 1974 catch, suggesting highly effective avoidance or poor survival of that year class -- additional data may provide an explanation.

Age 6 fish comprised about 47% of the 1974 catch. Again, no fish older than age 8 were caught, implying the absence of 1964-1965 year class fish in our study area by 1974.

The data (Table B62) suggest that although sexually mature adults constituted the bulk of the catch, a severe decline in numbers of fish older than age 6 occurs and fish older than age 8 are not collected. Juvenile fish were caught only in limited numbers, but our data probably grossly underestimated the abundance and distribution of these fish on a lake-wide basis.

Table B62. Length distributions of year classes of lake trout taken from southeastern Lake Michigan near the D. C. Cook Nuclear Plant. Data are represented by age class for 1973 and 1974 catches. First column below each year class is age-group of fish captured during 1973; second is age-group of fish captured during 1974.

Year Class	1973		1972		1971		1970		1969		1968		1967		1966		1965	
Age-Group (at capture)	0	I	I	II	II	III	III	IV	IV	V	V	VI	VI	VII	VII	VIII	VIII	IX
Length (mm)																		
>860																		
840–859																		
820–839															1			
800–819																	1	
780–799												1	1			1		
760–779											1			1	7	3		
740–759												3	1		6	4		
720–739											1	3	4	2	13	3	1	
700–719											3	14		4	9	2		
680–699										1	7	11	12	3	4	3		
660–679										4	15	10	6	2	3	2		
640–659										2	27	7	17	3	2			
620–639									1	2	6	5	16	5	2			
600–619										3	11	4	10	2				
580–599											6		3		1			
560–579										2	1	1	1	1				
540–559									1			1			1			
520–539												1	1					
600–519																		
480–499																		
460–479								1										
440–459					2	2		1										
420–439						1												
400–419						1												
380–399						1												
360–379																		
340–359					1	1												
320–339																		
300–319				1														
<300		2	6	3														
Total		2	6	4	3	6		2	2	14	78	61	72	23	49	18	2	
Length Range		112–139	130–158	258–300	351–446	346–450		455–460	576–657	592–715	598–782	547–810	542–815	591–780	573–857	680–800	754–832	
Mean Length ± S.E.		125 ±14	141 ± 4	280 ± 9	412 ±31	412 ±17		457 ± 3	617 ±41	656 ±10	668 ± 4	695 ± 6	670 ± 5	687 ±10	735 ± 7	744 ± 9	793 ±39	
Percentage composition of total yearly catch		1.5	2.8	3.1	1.4	4.6		1.5	0.9	10.8	36.8	46.9	34.0	17.7	23.1	13.8	0.9	

Mean length and standard error of fish captured during 1973-1974 are presented in Fig. B81. Numbers of fish of similar age (but different year classes) were pooled to provide an estimate of mean length at a given age. The data showed a reasonably normal growth curve with rate of growth highest during the first 5 yr, then declining somewhat at sexual maturity. Oldest fish showed a mean length of 799±9 mm and exhibited no major decrease in rate of growth. This suggested that lake trout older than age 8 are removed from the population while still actively growing, or that we failed to capture them because of their large size or because they were not present in our study area. Rybicki and Keller (1976) concluded from 1975 indices of relative abundance of lake trout and a catch curve constructed from the mean catch-per-effort for the period 1970-1975 that, "for all practical purposes the 1964, 1965 and 1966 year classes of lake trout are defunct" and that few lake trout survived beyond age 8. Although Rybicki and Keller did not include data from Michigan Statistical District MM-8 (which includes our study area), our data agreed well with their conclusions.

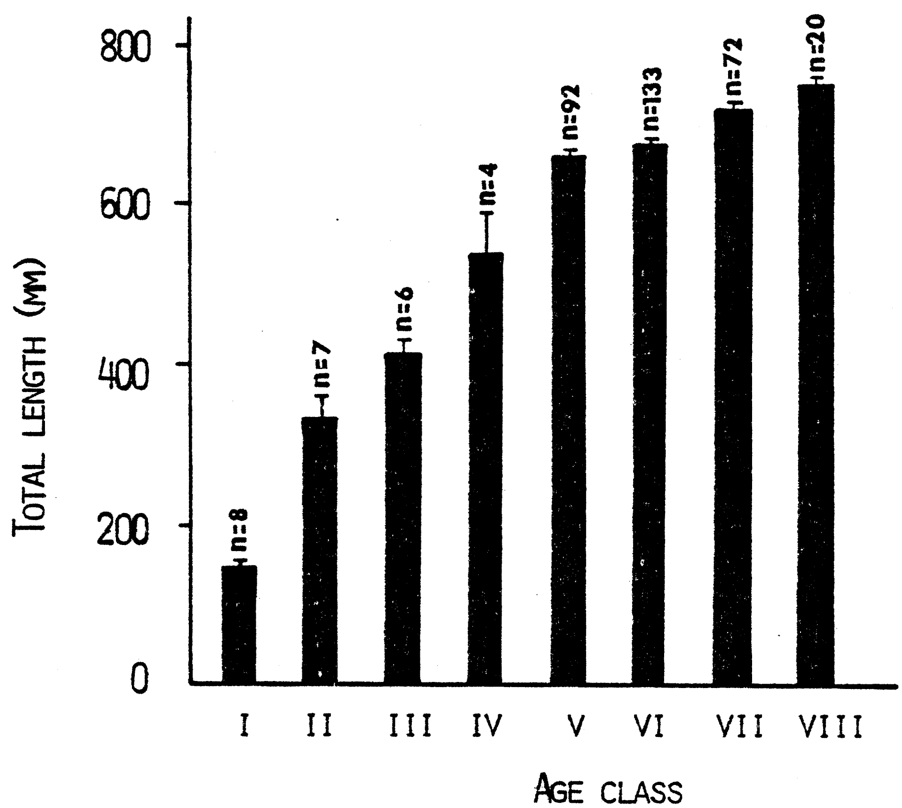

Fig. B81. Mean length (bars) and standard error (lines) of age classes of lake trout captured during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan. Numbers (N) represent sample size.

Comparing our data (Fig. B81) with age and growth data compiled by Limnetics (1976) for lake trout caught in Lake Michigan, fish captured in our study area showed higher mean lengths at given age than did fish taken from other (primarily more northerly) portions of the lake. It is possible that lake trout may grow more rapidly in southern portions of the lake.

Clip marks (associated with planting locations) indicated approximately 88% of lake trout that we captured were planted within a 160-km radius of the study area; most were probably planted considerably closer. The remainder of the fish were planted at distances more than 200 km from the study area, 5% at distances more than 320 km. Fish that were captured had been planted at locations which included: Grand Traverse Bay, Charlevoix, Petoskey, Gills Rock, Kewaunee and the Milwaukee Reef complex, although most were planted at locations close to the study area. These data indicated that limited cross-lake movements (from Wisconsin to Michigan waters) of fish occurred as well as movements from northern to southern basin waters. Since several fish planted at locations distant to the study area were captured during the fall, it may be concluded that a small percentage of lake trout do not return to the location where they were planted during spawning season.

Sea lamprey scars observed on lake trout captured during 1973-1974 in the study area are summarized in Table B63; data include fresh and healed wounds. Twenty-two percent of total numbers of fish caught were scarred, but less than 1% of these scars were fresh wounds, indicting that present wounding rates may be low in this area of the lake. Three percent of the fish showed multiple scarring; six separate scars were counted on one 772-mm fish. Percentage of fish scarred increased dramatically with increasing size (and age) of fish. Younger fish, most of which were sexually immature, were not frequently scarred. Location of scars was examined; 52% were posterior to the anterior base of the dorsal fin, 51% occurred on the right side of the fish and 84% were below the lateral line.

All lake trout captured during 1973-1974 were taken at water temperatures ranging from 2.0 to 17.9 C (Fig. B82). Forty-nine percent of standard series fishing efforts were conducted when water temperatures were between 2.0 to 17.9 C; 24% were conducted when temperatures were between 8.0 and 11.9 C. Fifty-nine percent of the total number (1973-1974) of fish were caught when water temperatures were between 8.0 and 11.9 C, 35% at temperatures between 12.0 and 15.9 C. But, during 1974, 70% of total standard series catch of lake trout occurred when water temperatures were between 10.0 and 11.9 C. Maximum catches of fish occurred at temperatures which closely approximate the preferred temperature range indicated in the literature (12 C - Ferguson 1958; 10 C - Daly et al. 1969). Scott and Crossman (1973) reported a spawning temperature preference range for lake trout from 8.9 to 13.9 C. Our temperature data from 1974 suggested a tendency for larger (750 mm or more) fish to be caught at temperatures between 9 and 12 C and smaller fish (adults less than 550 mm in length, juveniles and yearlings) to be captured at temperatures usually less than but occasionally greater than 9-12 C. However, since lake trout are

vulnerable to our fishing efforts primarily during fall when they move onshore to spawn, our temperature-catch data may reflect preferred spawning temperatures rather than non-spawning temperature preferences.

Table B63. Sea lamprey scars observed on lake trout captured during 1973-1974 at Cook Plant study areas, southeastern Lake Michigan.

Total Length (mm)	Tot. No. Fish	No. Fish Scarred	Percentage Scarred	Number of Scars			
				1	2	3	4 or more
850-899	1	0	0				
800-849	4	3	75	1	2		
750-799	37	11	30	9		1	1
700-749	89	30	34	26	3	1	
650-699	122	25	21	25			
600-649	57	7	12	6	1		
550-599	10	1	10	1			
<550	29	0	0				
Total	349	77	22	68	6	2	1

Longnose Sucker --

In 1973, 86 longnose suckers were caught by standard series nets, while in 1974, 99 fish were caught (see Tables B6 and B9). These similar catches indicate probably no population change between the 2 yr. The slight increase in catch during 1974 can be accounted for by increased fishing effort and variation in temporal distribution due to thermal dissimilarities between periods of the 2 yr.

Some of the 15% increased 1974 catch can be attributed to increased fishing efforts in November and December 1974 (see Fishing Effort). Monthly catches between years were similar. Some catch variation occurred between years in April and May. Average monthly temperatures during these months were similar between years, but temperatures in March 1973 were warmer than March 1974 (see Fig. B6). The warmer March temperatures may have initiated spawning earlier in 1973 than in 1974.

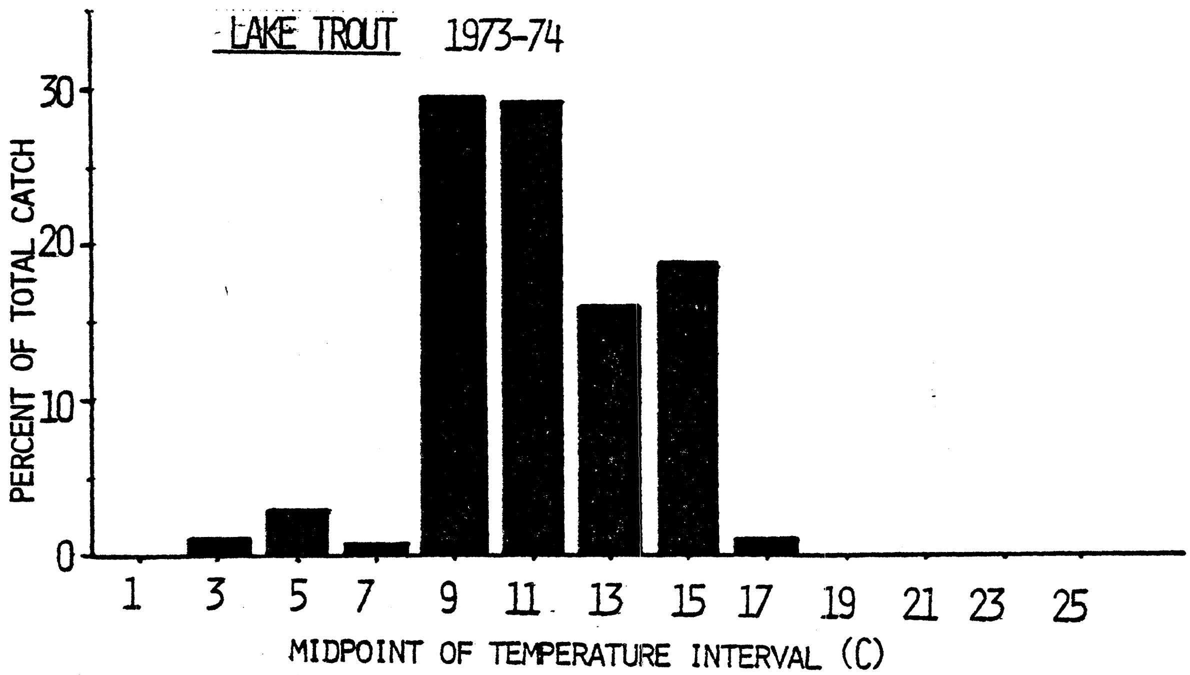

Fig. B82. Temperature-catch relationships of lake trout as shown by the percentage of the standard series catch captured in each 2 C interval during 1973-1974 at Cook Plant study areas, southeastern Lake Michigan. All gear catches were combined. (N = 262 fish for 1973 and 212 for 1974).

Gonad data for 1973 revealed two spent females were captured in March (Jude et al. 1975, page 200). In 1974 spent females were not collected until April sampling (Table B64). Although numbers of fish were too low to indicate conclusive evidence of spawning times, these data do point to earlier spawning in 1973. Apparently most longnose sucker spawning occurred in April, but ranged between March and May. Low numbers of fish caught in the study area during the spawning season indicate that suckers were spawning elsewhere (probably in tributaries to the lake) during both years. White suckers also spawn outside the study area (see White Sucker). Dryer (1966) indicated that smaller catches of longnose suckers from various depths of the Apostle Islands region of Lake Superior during spring and early summer may reflect a temporary stream residence for spawning.

Catch variation in April and May of the 2 yr may have been caused by the supposed earlier spawning in 1973. If most spawning occurred in March and early April 1973, by mid-April (when we sampled) adults would be returning to the study area and catches would be high -- as they were. May catches were even higher as more adults returned to the study area causing higher abundance.

Table B64. Monthly gonad conditions of longnose suckers as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1974 in southeastern Lake Michigan. All fish examined in a month were included.

Gonad Condition	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.	1	1	1			1					
Mod. dev.	1		2		4	4		2	1		
Well dev.	6	1	3		4					7	3
Ripe-run.											
Spent			2	11	9	15					
					Males						
Poorly dev.	1			4		1				1	
Mod. dev.	15	2	1	1	7	11	1	1		6	5
Well dev.	7		1	1	6					2	
Ripe-run.											
Spent				12	1	5					
					Immature						
		1	1				1		2		

Largest monthly catches of longnose suckers during both years occurred in July (see Tables B6 and B9). These catches (mostly in gill nets) were considerably larger than any other month's catch. The cause for these high catches is unknown. Upwellings occurred while gillnetting in July of both years and may have concentrated the fish inshore. But upwellings also occurred while gillnetting during August of both years and September of 1973, yet no concentration of fish occurred. Preliminary data for July 1975 showed no upwelling occurred and no large catches of longnose suckers occurred. This finding supports the theory that cold water from upwellings concentrated the fish in July 1973 and 1974, but unknown factors may have caused the high catches. Emery (1970) found that white suckers moved shoreward with warm water when an internal seiche brought cold water inshore in Little Dunks Bay, Lake Huron.

Longnose suckers, like white suckers, were caught during all months of the year (see Tables B6 and B9). These two species stay in the inshore regions throughout the year (except during spawning) and do not show pronounced movements with seasonal temperature changes like many other species (see General Diversity and Distribution of Fish Species). Data from the Apostle Islands region of Lake Superior suggest that some longnose suckers move offshore (18-53 m) in the fall (Dryer 1966).

More longnose suckers were gillnetted at Warren Dunes than at Cook during both years (Table B65). Abundance of white suckers was also greater at Warren Dunes. Although exact causes for this spatial difference are unknown, suckers may be attracted to the Dunes area because of the presence of a small stream at the south end of the park (see Fig. B1). Spatial distribution data for most of the other species indicated that fish populations were similar between Cook and Warren Dunes -- the control area. Some differences which do exist can be accounted for by establishment of localized populations (e.g., slimy sculpins and johnny darters) on the riprap at Cook. Greater abundance of both sucker species at Warren Dunes may indicate that there are some environmental differences between Cook and the control area, possibly related to the small stream at the Dunes.

Table B65. Number of longnose suckers caught by standard series gill nets in 1973 and 1974 at Cook Plant area stations, southeastern Lake Michigan.

	1973 Stations				1974 Stations			
	Cook		Warren Dunes		Cook		Warren Dunes	
	C-6 m	D-9 m	G-6 m	H-9 m	C-6 m	D-9 m	G-6 m	H-9 m
Day	0	5	0	15	2	5	27	14
Night	15	4	28	11	12	7	18	9

In 1973, more fish were gillnetted at night, but in 1974 day and night catches were about equal (Table B65). Increased day catches at 6-m stations (especially station G which is nearest the Warren Dunes stream) caused 1974 day catches to be high. May and July day gill nets at station G accounted for 11 and 14 fish respectively. What factors caused these increased catches are largely unknown.

Longnose suckers probably exhibit an inshore-offshore movement similar to that of white suckers. Emery (1973) in Little Dunk's Bay, Lake Huron

rarely observed longnose suckers during the day but they were seen commonly at night at 8-12 m. During a diel series of gill net sets in July 1973 (see White Sucker), we caught one longnose sucker at 6 m between 2000 and 2230 and another between 2300 and 0430 at 9 m. Although these data are not conclusive they do suggest that longnose suckers move inshore at dusk and offshore probably just before dawn. High night catches at 6 m (Table B65) suggest that fish move into these depths at night. Similar day-night catches at 9-m stations indicate the fish are probably at this depth and deeper depths both day and night.

While gill netting accounted for 91% in 1973 and 95% in 1974 of the total standard series longnose sucker catch, some fish were trawled and seined. Only five fish were trawled in 1973 and two in 1974. Most larger longnose suckers can effectively escape the trawl. Three fish were seined in 1973 and three in 1974, indicating juveniles of this species do range into the shallowest depths of the lake.

The majority of longnose suckers caught by total fishing efforts in 1974 were in two size ranges: 365-424 and 465-524 mm (Table B66). In 1973 the majority of fish were also in two size groups (275-374 and 425-524 mm), but size ranges were different. Evidently fish in the 275-374-mm size range in 1973 were part of a large year class or classes which presumably grew into the 365-424-mm size range during 1974.

A 75-mm sucker seined in March was undoubtedly a yearling (Table B66). The three fish caught in August and October (size range 86-105 mm) were probably in their second year of life. Bailey (1969) calculated longnose suckers in Western Lake Superior to be 81 and 150 mm at the end of 1 and 2 yr of life respectively. In Yellowstone Lake, Wyoming, Brown and Graham (1954) calculated longnose suckers to be 51 and 122 mm at the end of 1 and 2 yr of life respectively. Although our data are extremely meager and the 2-yr-old fish had not finished growing, these data suggest that southeastern Lake Michigan longnose suckers were growing at a slower rate than in Lake Superior, but slightly greater than in Yellowstone Lake.

Very few small fish (especially in the 125-274-mm size range) were caught during both years, and these were collected mostly with seines (Table B67 and Table B49 in Jude et al. 1975). There may be a paucity of small fish in the study area or they are at depths we do not sample. We do not fish extensively between 2 and 6 m, but gill nets set at beach station A (1.5-3 m) yielded no small suckers. It is also possible that small suckers are not suseptible to gill nets. Very low catches of small white suckers also occurred in the study areas. Scarcity of juveniles of both species may indicate that these individuals do not reside in the study areas, but inhabit other areas of the lake. As noted some YOY white suckers (30-50 mm) were collected from the small stream near Warren Dunes, so that areas such as these may serve as nursery streams until they reach a larger size.

Large gill net catches at 21 m (station E) revealed that longnose suckers ranged extensively into deeper water (Table B67). This depth range

Table B66. Monthly length-frequency distribution of all longnose suckers caught during 1974 at Cook Plant study areas. Catches from all gear are pooled.

Length Interval (mm)	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
65–84		1										1
85–104							1		1			2
105–124									1			1
345–364			1	1		3						5
365–384			1	8	5	1						15
385–404	2	2	2	12	14	13						45
405–424	1			5	5	15	1					27
425–444	1				2	4		1		1		9
445–464	4				1	3				1	1	10
465–484	8	1	1	1	3	1		1		1	3	20
485–504	8			1		1				5	1	16
505–524	5	1	3		1					3	1	14
525–544	1		1	1				1		4	1	9
545–564	1		1									2
565–584			1								1	2
585–604									1	1		2
Totals	31	5	11	29	31	41	2	3	3	16	8	180

Table B67. Length-frequency distribution of all longnose suckers collected during 1974 by gill nets, seines, trawls and impingment from ten stations in Cook Plant study areas.

Length interval (mm)	Fishing Gear: Gill net	Trawl	Seine	Impingment	Station: S[1]	B	A[2]	C	D	G	H	4[3]	T[4]	E
65-84			1			1								
85-104		1	1			1		1						
105-124			1			1								
345-364	5							1	1	2	1			
365-384	15							5	2	3	4	1		
385-404	44	1					2	8	5	22	4		1	3
405-424	26			1	1		1	7	1	9	7			1
425-444	9							2	1	3	1			2
445-464	10							1	2	1	1			5
465-484	20						2	2	2	2	2	1		9
485-504	16								1	1	2			12
505-524	14						1	1	1	3				8
525-544	9								2	1			1	5
545-564	2												1	1
565-584	2						1							1
585-604	2										1			1
Totals: Day	71		1	1	1	1	3	2	5	27	14	2	3	15
Night	103	2	2			2	4	26	13	20	9			33

[1]Station S stands for impinged fish at the Cook Plant.

[2]The only fish caught at station A were gillnetted.

[3]Station 4 is at 12 m off the Cook Plant.

[4]Station T is at 12 m off Warren Dunes.

is in contrast to that of white suckers which were rarely caught at 21 m (see White Sucker and Table B60). Two April day sets at 12 m (Stations T and 4) also caught longnose sucker (Table B67). Interestingly, these nets caught suckers (two fish at Cook, three at Warren Dunes) while April day sets at 6 and 9 m collected no suckers at Cook or Warren Dunes. These data plus the other monthly standard series catches indicated that during the day, 9 m is probably the shallow end of the longnose sucker's depth range. This range extends to 21 m and possibly deeper depths in the lake. Scott and Crossman (1973) reported that longnose suckers have been caught at 183 m in Lake Superior. Dryer (1966) found that, except for one longnose sucker caught at 91-109 m, no suckers were taken deeper than 71 m and they were most abundant at depths less than 37 m in the Apostle Islands region of Lake Superior.

Fish caught at 21 m were generally larger than those caught at 6-, 9- and 12-m stations (Table B67). Scott and Crossman (1973) reported that white suckers tended to move offshore with age, but we have not found any evidence in the literature of this size-depth relationship for longnose suckers.

About equal numbers of males and females were caught during both years of the study (55% females in 1973 and 46% in 1974). The difference in ratios between the 2 yr does not appear to be a notable change. Scott and Crossman (1973) stated that females achieved a greater maximum size than males. Our data also suggested this size-sex relationship. Of the fish 500+ mm in length, 84% (16 fish) in 1973 and 53% (20 fish) in 1974 were females. The longest fish caught in 1973 was a 565-mm (2400 g) female; longest in 1974 was a 594-mm (2500 g) female. The heaviest fish caught was also a female and weighed 2650 g. The largest longnose sucker reported in the literature (Harris 1962) was caught in Great Slave Lake, Canada and measured 642 mm (fork length) (3300 g).

Three fish caught in 1973 and 1974 had lamprey scars. Incidence (based on all fish caught) was 1.9% in 1973 and 0.6% in 1974. These suckers, like the scarred white suckers, were large in size (495, 544, 558 and 565 mm).

One longnose sucker caught in 1973 and four in 1974 had neoplastic lesions on the head (usually on the lips). This growth was identical (under gross examination) to that found on some white suckers caught in the study areas (see White Sucker). Lengths of the longnose suckers collected with the growth were: 445, 463, 475, 493 and 500 mm. All were males, three were caught off Cook and two off Warren Dunes.

Like white suckers, longnose suckers were caught over a wide temperature range (0-23.9 C) during 1973 and 1974 (Fig. B83). This wide range is a result of fish staying in inshore waters throughout the calender year. It further indicates that, like white suckers, longnose suckers probably do not move extensively to find discrete water temperatures.

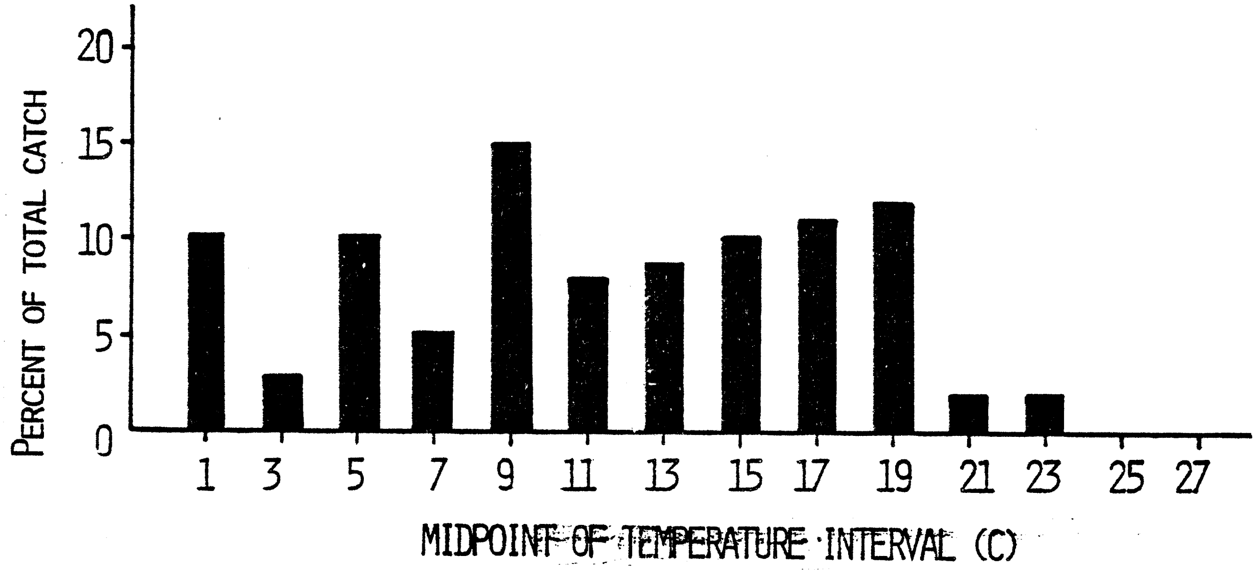

Fig. B83. Percentage of the combined total standard series catch of longnose suckers collected from different water temperatures at Cook Plant study areas, 1973 and 1974.

Apparently longnose suckers preferred slightly colder water than white suckers. Very few longnose suckers (4% of the total standard series catch) were caught in temperatures above 20 C, while several white suckers (14% of the total standard series catch) were caught (Fig. B83). Also more longnose suckers (52% of the total standard series catch) were caught in water temperatures between 0 and 11.9 C than white suckers (33% of the total standard series catch).

Gizzard Shad --

Gizzard shad numbers increased in the study area in 1974. In standard series fishing 84 shad were caught, comprising 0.07% of the 1974 catch. These fish were 87-490 mm and weighed 5.6-1450 g. During 1973 only 23 gizzard shad were taken, accounting for 0.01% of the standard series catch. Age-size class information employing total length data for Lake Michigan gizzard shad were not available. However many of the shad we caught evidently were YOY and yearlings. Thirty-two of the 84 standard series shad in 1974 were classified as immature during gonad inspection and Bodola (1966) notes that this species usually matures as it reaches age 2.

During 1974 gizzard shad were gillnetted (30 fish), seined (54 fish) and impinged (26 fish). In 1973 all shad caught in standard series gear were seined. Seine catches in both years consisted primarily of immature fish which seemed to congregate in the beach zone both early in the year (January-May) and at the end of the year (October-December) (Tables B68 and B69). In a study of western Lake Erie, Miller (1960) also noted YOY gizzard shad concentrated near shore. No gizzard shad were trawled in 1973 or 1974, but data from 1975 indicated that this species is susceptible to trawling. Thirty gizzard shad were trawled in 1975. These ranged from 65 to 124 mm

and all but one were taken in December. Larger adult shad appeared to avoid the trawl, as did large adults of other species in the area, notably salmonids.

Adults in spawning condition were rarely observed. During 1973-1974 only one shad with well developed gonads was captured (Table B68). This was a male taken in a supplementary gill net at station A (N Cook) in March, 1973. Spawning probably occurs elsewhere, perhaps in the St. Joseph River or at another location along shore. The literature indicates that gizzard shad spawn during spring and summer (Scott and Crossman 1973, Bodola 1966) in quieter water of lakes, rivers, sloughs and ponds (Miller 1960, Scott and

Table B68. Monthly gonad conditions of gizzard shad as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 and 1974 in southeastern Lake Michigan. All fish examined in a month were included except poorly received specimens.

Gonad Condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Females												
Poorly dev.					1				18	9	1	
Mod. dev.								1	2	1		
Well dev.												
Ripe-running												
Spent									2	3		
Males												
Poorly dev.									16	3		
Mod. dev.								1	1	3		
Well dev.			1									
Ripe-running												
Spent												
Immature												
		2	10	4	24					2	19	9
Unable to distinguish												
	1		1	3	3	1				1	3	4

Table B69. Monthly length-frequency distribution of gizzard shad caught during 1973-1974. All fish captured are shown, except impinged fish.

Length interval (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
45-54											1	
65-74			1								1	
75-84											4	
85-94			2		1					1	8	1
95-104			1	1	2						3	2
105-114	1	1		2	5						4	4
115-124		1	3		11						1	4
125-134			2	3	21					1	1	1
135-144			1		8							1
145-154			1	1	1							
155-164			1									
165-174										2		
175-184						1						
205-214										1		
225-234										1		
235-244									1			
245-254										1		
255-264									1	2		
275-284										2		
285-294									1			
295-304										1		
315-324										1		
345-354									1			
355-364										2		
365-374									1			
375-384									2			
395-404									3			
405-414										2		
415-424			1						7	1		
425-434									5	1		
435-444									3			
445-454									5	3		
455-464								1	3			
465-474									2			
475-484									1			
485-494								1	2			
505-514									1			

Crossman 1973). Bodola (1966) observed spawning taking place over growths of *Cladophora*, *Myriophyllum* and *Butomus*. Spawning occurring at the relatively warm water temperatures of 10.0-21.1 C was reported by Miller (1960) for the U.S. generally, while Bodola (1966) gave a range of 15.0-23.3 C for western Lake Erie, with most spawning taking place at 19.5 C or warmer. It should be noted however that Bodola's observations were based on a single incidence of spawning.

Initially the Cook Plant area may not have offered attractive spawning grounds for gizzard shad, since the substrate was largely sand, and the study area is in a wave-influenced zone. In view of increasing abundance of this species in the study area and the accumulation of *Cladophora* on the intake structures (Dorr and Miller 1975) it is possible that in the future gizzard shad might be attracted to the intakes for spawning, though this has not been observed to date. YOY are also attracted to aquatic vegetation (Miller 1960) and could be attracted to *Cladophora* on the intakes. Algal growths on the intakes could serve as a food source for this partially herbivorous species.

That spawning occurred outside the study area was indirectly supported by the fact that we did not capture many adults until after the spawning season (Tables B68 and B69). Only three adults were captured in total 1973-1974 fishing before September. Alternatively, shad near Cook may have spawned briefly while we were not sampling the area, which is a less likely theory since the literature describes a prolonged spawning season for the species (Scott and Crossman 1973, Bodola 1966).

During 1974 standard series fishing, more gizzard shad were caught at night (74 fish) than in daytime (10 fish), a trend also observed in 1973 (Jude et al. 1975). There was no consistent preference for any station in either year in standard series fishing (Table B70). The large seine catch at station B (S Cook) in May, 1974 was due mainly to a single night seine haul and consisted entirely of immature fish, probably yearlings. Young gizzard shad are known to school, though this activity usually disappears by the end of the first year of life (Miller 1960). The large May catch may therefore have been the result of residual schooling behavior. The catch at station B may also have been due to the unusual habitat at that station. Station B has a more rocky substrate than the other two seining stations because of pieces of riprap, scrap iron and cement left over when the safe harbor was removed. There are also growths of *Cladophora* on the rocks and cement there which might have attracted young shad.

Supplementary fishing in 1974 yielded five shad in May seines (104-133 mm, 10.0-24.5 g) and 17 in gill nets (257-507 mm, 176-1659 g). All gillnetted fish were caught in nets set perpendicular to shore at beach station A (N Cook). Supplementary gill net data suggest alongshore movement of gizzard shad, perhaps in relation to feeding, or migration to and from the St. Joseph River. Shad gillnetted at station A were captured during August-October.

Table B70. Gizzard shad standard series adjusted catch for 1973 and 1974 listed by gear type, station and month.

1973

Gill Net - none

Seine	STA A- Cook	STA B- Cook	STA F-Warren Dunes
Oct	1	0	0
Nov	8	5	9

1974

Gill Net	Cook Stations		Warren Dunes Stations	
	C - 6m	D - 9m	G - 6m	H - 9m
May	0	0	1	0
Aug	1	0	0	0
Sep	4	1	11	4
Oct	1	3	1	3

Seine	STA A- Cook	STA B- Cook	STA F-Warren Dunes
Mar	4	1	0
Apr	0	0	4
May	1	35	7
Jun	1	0	0
Oct	0	0	0

Total fishing in 1974 (unadjusted catch) produced gizzard shad during February-June and August-December. Most were caught in May (40 fish) and in September (32), October (13) and December (13). Twenty-six were impinged in 1974, in contrast to 1973 when only one was impinged. But impingement sampling was less extensive in 1973, so this does not necessarily reflect a real increase in numbers of shad susceptible to impingement in 1974 (see SECTION E).

Gizzard shad displayed several seasonal peaks of abundance which may describe either alongshore or inshore-offshore movement in the study area. These movements were often segregated with respect to juvenile and adult fish. Similar patterns have been observed in Lake Erie by Eisele and Malaric (1976). In 1973 shad were abundant in our study areas only during September-November. September and October catches consisted mainly of adults with poorly to moderately developed gonads. Gizzard shad collected in November 1973 were all sexually immature; These fish were undoubtedly YOY spawned that summer. During 1974 large numbers of shad were captured from March through May and these fish were probably all yearlings. Adults were not numerous until September and October. By December YOY dominated our shad catches. Eisele and Malaric (1976) have attributed shad impingement abundance peaks at the Monroe Detroit Edison Power Plant on Lake Erie to turbidity, change in water temperature, schooling behavior and variation in intake pump speed. Some of these factors may also contribute to shad peak catches in our study area.

During 1973-1974 total fishing, gizzard shad were taken at temperatures that ranged from 1.6 to 22.7 C. Standard series fishing showed peak catches at two temperature intervals, 11 and 19 C (Table B71). The apparent bimodal pattern (at 11 C and 19 C) was due to larger catches of shad in November 1973 and May 1974 at the 11 C interval and to a peak catch in September 1974 at the 19 C interval. These peaks are not thought to reflect actual temperature preference but rather to parallel migrations of this species through the study area. The literature indicates that gizzard shad are very tolerant of warm water. Gammon (1971) observed them in the Wabash River (Ohio) in 34 C water. Several laboratory studies of adult gizzard shad temperature tolerance have been conducted. Brett (1956) noted that adults acclimated to 25 C had an upper lethal temperature of 34.3 C and a lower lethal temperature of 10.8 C. Reutter and Herdendorf (1974, 1976) found that 49 Lake Erie gizzard shad caught in autumn had a final preferendum of 20.5 C. Acclimated to 15.9 C, their critical thermal maximum was 31.7 C. The authors stated that gizzard shad were quite sensitive to handling and may actually have a higher temperature tolerance than indicated by the laboratory tests.

The gizzard shad has frequently been considered a pest species. Originally this fish was regarded as valuable forage for sport fish because it provided a direct link between plants (as an algae feeder) and shad predators like large- and smallmouth bass, crappies and white bass (Tiffany 1921). But gizzard shad are prolific spawners and capable of such rapid growth that by the middle of their second year few predators can feed on

Table B71. Temperature-catch relationships of gizzard shad as shown by the percentage of the standard series catch captured in each 2 C interval during 1973-1974 at Cook Plant study areas, southeastern Lake Michigan. All gear catches combined.

Midpoint of temp. interval (C):	3	5	7	9	11	13	15	17	19
% of 1973-1974 std. ser. catch:	3.1	0.0	8.4	7.4	45.6	7.7	0.9	5.6	21.2

them (Scott and Crossman 1973). They are of limited value as a sport or commercial species due to their bony flesh. Some sources advocate use of gizzard shad as livestock feed and fertilizer (Miller 1960, Scott and Crossman 1973). Shad experience spring and fall die-offs and also winter-kill easily, creating disposal problems in some areas (Bodola 1966, Miller 1960). They have also been reported to clog water intakes (Eisele and Malaric 1976, Bodola 1966, Miller 1960). Tolerant of warm temperatures, this species is attracted to thermal plumes (Miller 1960) and might therefore occur more frequently at Cook stations than at Warren Dunes in the future. However, relatively low numbers of this fish compared to our total catch make gizzard shad a questionable indicator species for detecting any Cook plant thermal effects.

The general increase of gizzard shad observed in catches at Cook and Warren Dunes during 1973-1974 can be expected to continue. Bodola (1966) documented overall increases of this species in commercial catches in the Great Lakes from 1939 to 1957. Lake Erie in particular experienced rapid growth of its shad population since 1950. Bodola attributed the change to human alteration of the environment but did not elaborate. Miller (1957) in contrast suggested that shad have become more common in the Great Lakes region as a result of the warmer climatic regime there during the past 50 yr.

Brown Trout --

During 1974, 51 brown trout were captured in standard series fishing (Table B9); most in May (14) and June (13), none in January or December. In comparison, the 1973 standard series catch numbered 76 (see Table B6). Twenty-seven were caught in seines during 1974, 22 in gill nets and 2 in trawls. Twenty-seven were taken during the day, 24 during the night. During 1973, 20 were caught during the day, 56 at night. The 1973-1974 data do not suggest any consistent activity patterns, though it is known that large browns feed mostly at night. Data from 1973-1974 indicate little difference between numbers caught at the Cook Plant and at Warren Dunes.

Supplementary fishing in 1974 captured an additional 29 fish; 28 in gill nets, one in a seine. Total 1974 (unadjusted) catch of brown trout was 80. Range in size of all fish captured was 102-693 mm (12.6-4140 g). Preponderance of fish 100-200 and 400-550 mm is illustrated in Fig. B84. As is the case with other salmonid species, we captured relatively few 250-400-mm (juvenile) fish. Seasonal catches (from all fishing efforts) were lowest in January when one 420-mm adult was gillnetted. During March, a 133-mm juvenile and a 355-mm adult were seined, while gill nets captured four adults (425-595 mm). Two juveniles (142, 170 mm) and one adult (516 mm) fish were seined in April, nine adults (331-693 mm) were gillnetted. Peak numbers were taken in May and June (27 and 15 fish respectively). Ten juveniles (155-220 mm) were seined in May and 12 in June. The remainder were gillnetted and mostly adults (265-684 mm). One fingerling (102 mm) and one yearling (202 mm) were trawled during July, four adults were gillnetted. Catches were low for the remainder of the field season and consisted exclusively of large fish (294-648 mm) taken in gill nets, except for one small fish seined in October. These data support the movement patterns as described by Jude et al. (1975); large fish were present inshore March-May, moving offshore during summer to cooler, deeper water. A noticeable upwelling during July 1974 was probably responsible for the presence of adult fish in gill nets set inshore. Our 1973 data more clearly reflected the fall return of brown trout to inshore waters, although the 1974 fall catch did increase from the summer catch.

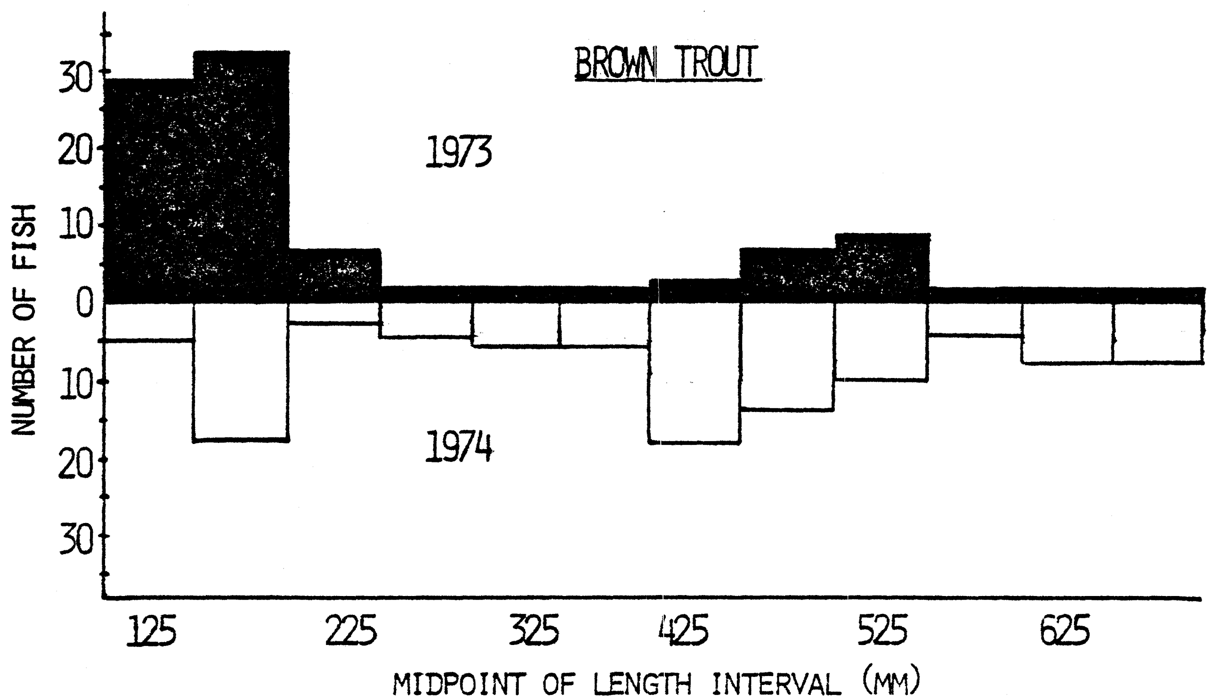

Fig. B84. Length-frequency histogram for brown trout caught during standard series and supplemental fishing activities in 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

Data from 1973-1974 seining efforts revealed the presence of juvenile (primarily yearling) fish in the beach zone most of the year (February-October). However, maximum abundance occurred in spring and early summer (May-June). Juvenile fish were also trawled at 6 and 9 m during June and July 1973-1974.

Gonad data (Table B72) suggested fall spawning; however, additional specimens with well developed and ripe-running gonads are needed to confirm an autumnal spawning period. Twice as many females were enumerated as males. Immature fish were taken February-October, but primarily in June.

Table B72. Monthly gonad conditions of brown trout as determined by inspection and classification of ovaries and testes. Fish were captured during 1973 and 1974 in southeastern Lake Michigan. All fish examined in a month were included.

Gonad Condition	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
					Females					
Poorly dev.	1	3	1	7	3	2	2		2	
Mod. dev.		3		1		2				
Well dev.				1	1		1	1	3	
Ripe-running										
Spent		9	7	4						
					Males					
Poorly dev.			1	7	1	4			2	
Mod. dev.					1		2	1	1	
Well dev.							1			
Ripe-running										
Spent		2	2							
					Immature					
	2	1	3	13	40	15	2	3	1	
					Unable to distinguish					
		1	2	4	3	1	1	2	4	2

We captured brown trout over a wide range (0-25.9 C) of water temperatures (Fig. B85). No clear trends were evident but our gill net data suggest 4-14 C as temperatures most commonly frequented by larger fish. Smaller fish were caught almost exclusively by seine, with indications that these fish preferred a higher temperature range than older fish.

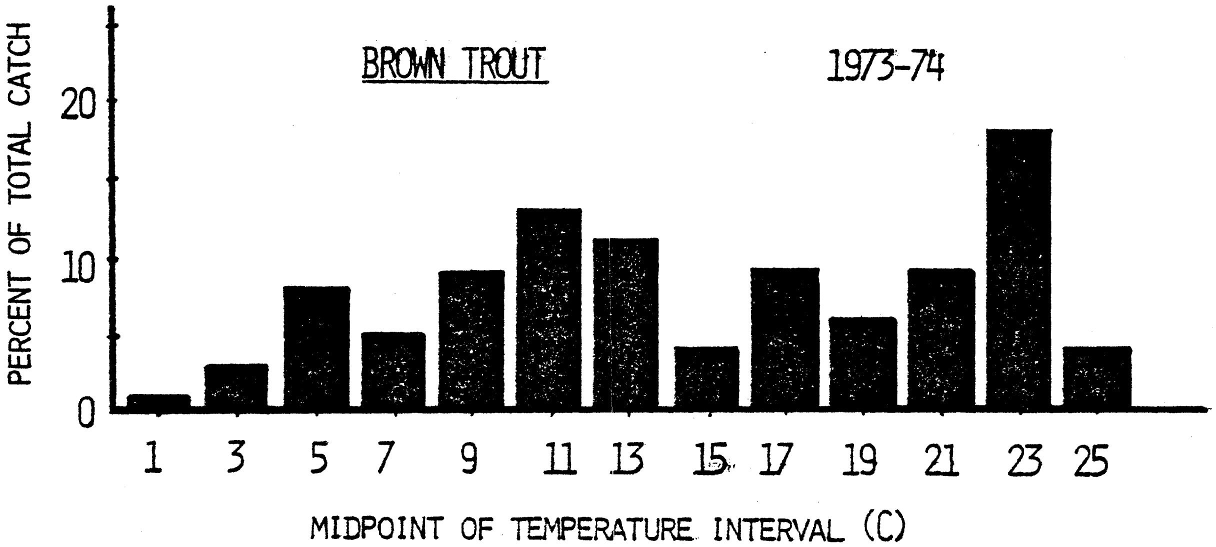

Fig. B85. Temperature-catch relationships of brown trout as shown by the percentage of the total catch captured in each 2 C interval during 1973-1974. All gear catches were combined (N = 99 for 1973 and 80 for 1974).

Bluegill --

In 1974, 46 bluegills were observed in standard series catches (see Table B9), two in non-standard series efforts and four were impinged. This is in contrast to 1973 when only 10 bluegills were caught (see Table B6). Bluegills from the 1974 catch ranged from 25 to 121 mm (mean of 39 mm). Weights ranged between 0.1 and 28.2 g (mean of 1.6 g). Beckman (1949) studied age-size classes of 8159 bluegills from 153 Michigan lakes and obtained the following average lengths for the different classes: 0 - 42 mm, 1 - 79 mm, 2 - 109 mm and 3 - 137 mm. Forty-four of the 52 bluegills we collected in 1974 were 42 mm or less. All but one were caught on or before 4 June. Thus, we concluded that most 1974 bluegills were 1-yr old when captured, since the species spawns from spring through mid-summer (Snow et al. 1970, Scott and Crossman 1973). Most fish probably entered Lake Michigan from adjacent lakes and streams.

A majority (32) of the 1974 bluegills were taken on 17 May during two seining efforts at Warren Dunes. Bluegills from this catch ranged from 25 to 40 mm, which probably reflects a concentration of immature forms in the inshore area at this time. Snow et al. (1970) mentioned that young bluegills frequent shallow zones of lakes in warmer weather and travel in schools.

Diurnal patterns for bluegill were not pronounced in 1974 data. In 1973, nine out of 10 bluegills were taken at night, while only 18 of 52 were caught at night in 1974. Fish of similar size classes were taken in both years so this difference does not seem attributable to age.

Bluegills were caught at more stations in 1974 than in the previous year and were observed earlier in the year in 1974 (March-August) than in 1973 (May-November). The species was found in cooler temperature regimes in 1974 (4.1-22.3 C) than in 1973 (10.0-24.0 C). Most bluegills in both years had been feeding near the time of capture. All eight stomachs examined from 1973 and 30 of 33 examined from 1974 contained food.

Longnose Dace --

Longnose dace occur as a small but apparently stable population in the area of the Cook Plant. Forty-one were collected in 1973 and 43 were collected in 1974 (Tables B6 and B9), all with seines. Few were collected at Warren Dunes (Tables B11 and B12) and most Cook Plant specimens were caught at station B (S Cook).

Longnose dace were present in the area all year but were most abundant in autumn (Tables B6 and B9). Primarily a river fish, though also inhabiting the inshore areas of lakes (Scott and Crossman 1973) including eastern Lake Michigan (Brazo et al. 1978), the fall increase in abundance in our area indicates that these fish were leaving the rivers with the onset of cold weather. Another possible reason for increased fall abundance is that YOY are being forced from preferred gravel-rock substrates into sandy regions of the study area. The wide temperature range over which this species was collected (2.5-25.5 C) further suggests that they were present in the inshore area all year.

Dace may remain in the beach zone, for they have only been collected by seining. The bottom-dwelling adults should have been available to the trawl if they were present at 6 or 9 m. Further indication of their paucity at these depths is their absence from traveling screen catches. None were impinged in 1973 or 1974; however six have been impinged through November 1975. They may be attracted to the riprap and the current at the intake structure. Brazo et al. (1978) showed that longnose dace in eastern Lake Michigan preferred gravel-rock substrates to sandy areas .

Longevity of the species probably contributes to stability of the population, 5 yr being the maximum age recorded by Kuehn (1949) and Brazo et al. (1978). According to their age and growth studies, most of our specimens were probably less than 3-yr old. Size ranged from 30 to 80 mm in 1973 with a mean of 49 mm; in 1974 the range was 32-88 mm with a mean of 57 mm. Gonad condition indicated that 56% of the fish in 1973 and 1974 were immature. As adults are benthic and prefer a rubble or gravel bottom (Scott and Crossman 1973, Brazo et al. 1978), the sand bottom in the area of the Cook Plant would not provide a preferred habitat for adults. Young longnose dace, having a well-developed swim bladder (McPhail and Lindsay 1970) are

pelagic in habit and probably have a wider distribution along the shore. Too few adults of determinable sex were present to provide any information about spawning season, but Scott and Crossman (1973) report spawning probably occurs from May through early July. Brazo et al. (1978) found peak spawning of longnose dace in eastern Lake Michigan occurred during late June and early July of 1975 and 1976.

Approximately 80% of the longnose dace were collected at night and nocturnal feeding apparently occurs as most of the specimens caught at night with intact stomachs contained food. Longnose dace were least abundant during daylight hours in surge-zone waters of eastern Lake Michigan (Brazo et al. 1978).

Chinook Salmon --

We caught 41 chinook salmon in 1974 standard series fishing (Table B9), most during September (13), none in January, March or October. Most were caught in gill nets (23) and seines (14); four were trawled. During the night 30 were captured, during the day 11. Night catches were also higher in 1973, indicating increased nocturnal activity or susceptibility to our fishing gear. Both 1973 and 1974 data showed little difference between numbers caught at the Cook Plant and Warren Dunes. Four fish were captured in supplementary gill nets, two each at night in September and October. Total 1974 unadjusted catch of chinook was 45. This does not include a few (89-100 mm) fish which may have been mistakenly identified as coho. Range in size of all chinook caught was 79-998 mm (4.2-12,080 g) with the 100-300-mm size group most abundant. Numbers of yearling and juvenile fish 80-225 mm dominated total numbers caught (Fig. B86), with numbers of adult fish 575-975 mm comprising a smaller proportion of total catch; fish 275-575 mm were poorly represented in total numbers caught. Small fish (79-120 mm) were seined in May-July as they were in May-June 1973. Seining and trawling data (1973-1974) indicated small chinook were most abundant inshore during late spring and early summer. Chinook gillnetted during 1974 ranged from an immature, 184-mm (69.2 g) fish to a 998-mm (12,080 g) male; most were captured between late August and early November. Combined data from 1973 and 1974 standard series gill net catches showed adult chinook were most frequently captured between late August and early November. This would indicate an autumnal onshore movement which correlates with the inshore fall-spawning habits characteristic of this species in Lake Michigan (Parsons 1975). The nearest major spawning river, the St. Joseph, is about 16 km to the north.

Average planting length for fingerling chinook is 60-70 mm (A. Lamsa, personal communication, Great Lakes Fishery Commission, Ann Arbor, Mich.). Although fish 79-97 mm were seined and trawled, a significant planting of fingerling chinook (1.8 million) took place during May-June 1974 in southern Lake Michigan in Indiana and Illinois waters. Therefore, little can be said as to whether or not natural recruitment of chinook occurred near our study area during 1974.

Although incomplete, 1973-1974 data (Table B73) showed an increase in the number of females and males with moderately and well developed gonads

during late summer-fall (August-October). Fish with spent or poorly developed gonads were taken primarily between November and June. Immature fish (captured predominantly inshore in seines) occurred from March to October.

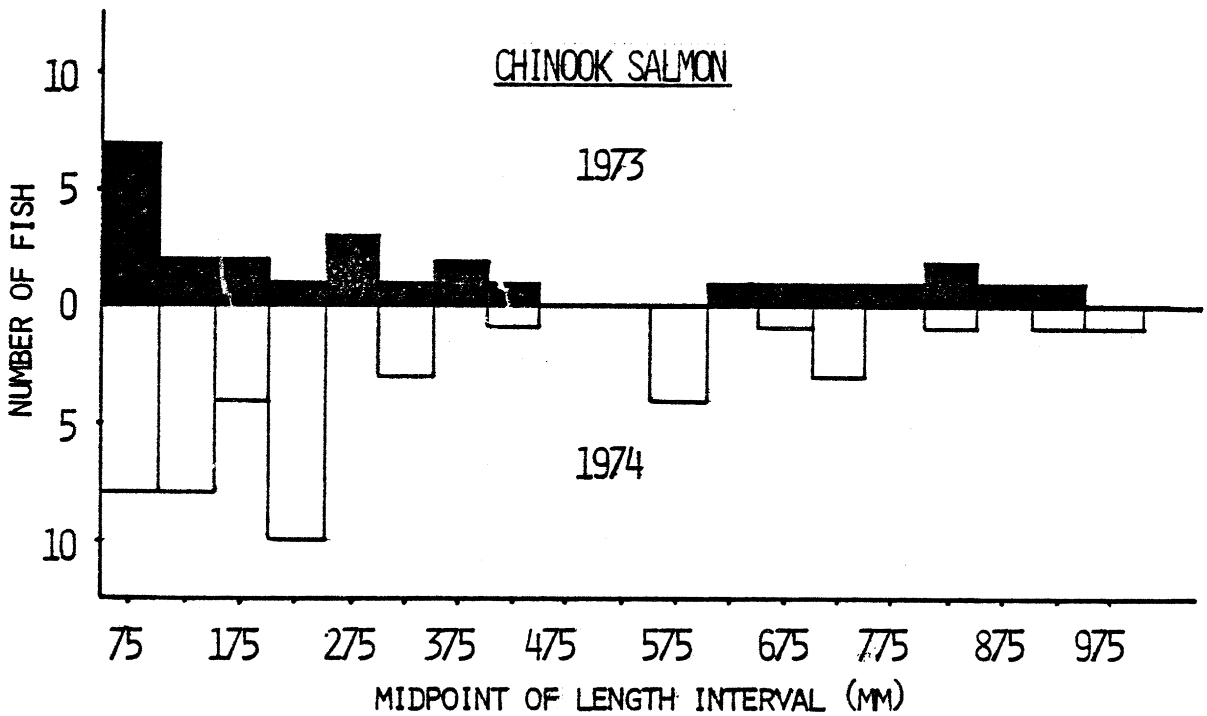

Fig. B86. Length-frequency histogram for chinook salmon caught during standard series and supplementary fishing activities in 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan.

Chinook were captured over the water temperature range 0-23.9 C (Fig. B87) but highest catch occurred at temperatures from 11 to 19 C. Fish longer than 560 mm were caught from 7 to 17 C with peak catch occurring at 11 C. Smaller fish 200 mm or less were captured over a wider range of temperatures (9-22 C), but most frequently at temperatures above 11 C. Juveniles and small adults 200-450 mm were caught primarily when temperatures ranged over 11-15 C.

Carp --

Standard series fishing accounted for 28 carp in 1973 (134-710 mm) and 27 in 1974 (38-760 mm). The majority of carp taken both years were between 500 and 700 mm (Fig. B88). Carp in 1973 were captured from April through October with the majority (14 fish) taken in June. During 1974 most were captured during May (7) and August (9).

Table B73. Monthly gonad conditions of chinook salmon as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 and 1974 in southeastern Lake Michigan. All fish examined in a month were included.

Gonad Condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females					
Poorly dev.			1	1			2		1	
Mod. dev.						2				
Well dev.										
Ripe-running										
Spent		2	1						1	
					Males					
Poorly dev.		1	2							
Mod. dev.						1		1		
Well dev.						2	4	2		
Ripe-running										
Spent										
					Immature					
	1	2	8	8	8	5	12	2		
					Unable to distinguish					
									1	1

During 1973, combining all gear and adjusting seine catches to catch-per-unit-effort, most carp were taken at Cook Plant stations (Table B74). In 1974, however, no difference in catch between Cook Plant and Warren Dunes stations (12 and 13 carp respectively) occurred.

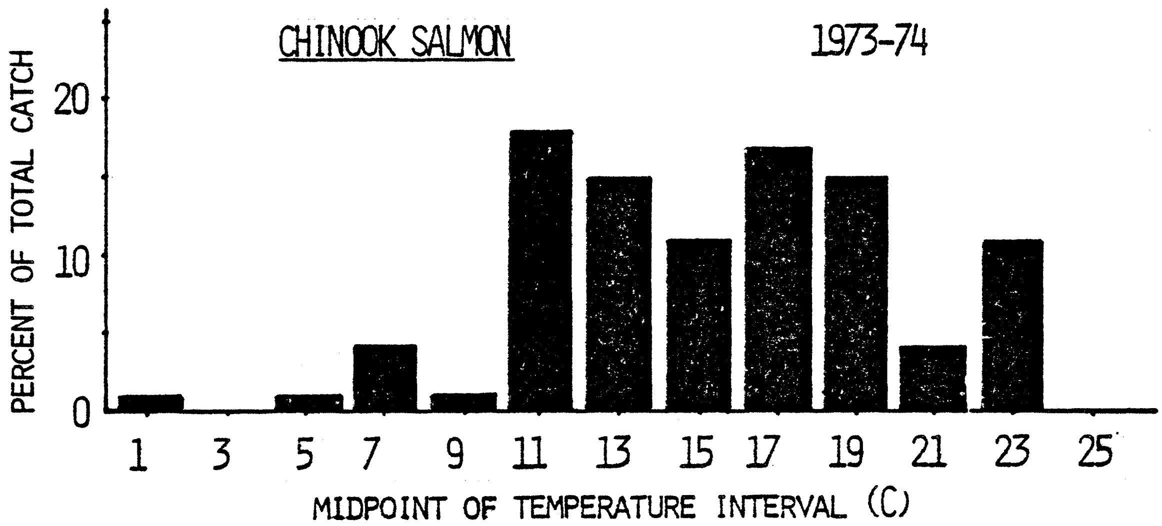

Fig. B87. Temperature-catch relationships of chinook salmon as shown by the percentage of the total catch occurring in each 2 C interval during 1973-1974. All gear catches were combined. (N = 27 for 1973 and 45 for 1974).

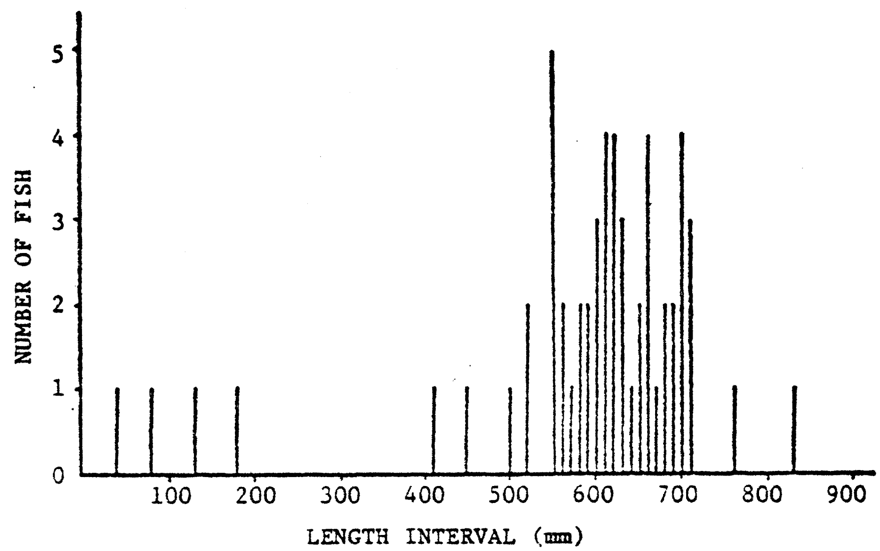

Fig. B88. Length-frequency histogram for carp captured by all gear in the Cook Plant vicinity, southeastern Lake Michigan, 1973-1974 combined.

Table B74. Total number of carp collected in standard series fishing gear (all gear combined) both day and night during 1973 and 1974 at Cook Plant study areas, southeastern Lake Michigan. (Seine catches at Cook were divided by two to make them comparable to Warren Dunes because there were two seining stations at Cook and one station at Warren Dunes.)

	1973		1974	
	Day	Night	Day	Night
Cook	3	12	6	6
Warren Dunes	0	6	9	4

Contrasting day and night catches during 1973 showed nocturnal catches were largest at all stations (Table B74). Differences between diurnal and nocturnal catches for 1974 were less well defined. Day and night catches at Cook Plant stations were equal while catches at Warren Dunes stations were larger during the day (9) than at night (4).

Carp were taken primarily in gill nets during 1973 with seines second in effectiveness. No carp were taken in trawls during 1973. Gill nets and seines during 1974 captured almost equal numbers of carp (13 and 12). Carp apparently are able to avoid the trawl, since only two were captured in 1974.

Carp are not thought to spawn extensively in Lake Michigan in the Cook Plant vicinity because of lack of habitat. However, a number of carp larvae have been collected only at Cook Plant stations in operational years. In addition, except for two fish (38 mm and 75 mm) seined in August 1974, we have never taken any YOY carp. Scott and Crossman (1973) reported that carp attained a length of 130-190 mm in their first year of growth in southern Ontario waters.

Gonad maturation data for 1973 showed well developed and a few ripe-running carp adults present in May and June, while for 1974 sexually well developed carp were present in June and July (Table B75). Spent individuals were collected in August 1973 and as early as July 1974. Jester (1974) reported carp to spawn in May-June in northern states with the onset of spawning occurring at 15.6 C. Scott and Crossman (1973) reported the onset of spawning at 17.0 C, and stated the time as early spring. Swee and McCrimmon (1966) reported spawning occurred May through August. The sex ratio of carp we captured in 1974 was 28 females:32 males; whereas, in 1973 it was 19 females:51 males.

Table B75. Monthly gonad conditions of carp as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1974 in southeastern Lake Michigan. All fish examined in a month were included.

Gonad Condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females					
Poorly dev.		1								
Mod. dev.		1	9		2	5	5			
Well dev.				3						
Ripe-running										
Spent					1	1				
					Males					
Poorly dev.										
Mod. dev.	1	2	4		2	3	6	6		
Well dev.				5	2					
Ripe-running										
Spent					1					
					Immature					
						2				

Combining temperature-catch data for 1973 and 1974 and adjusting it for fishing effort per temperature interval, shows carp were taken from 6 to 23.9 C (Fig. B89). Numbers of carp taken increased with a rise in temperature, with maximum catch in the 23 C interval. Pitt et al. (1956) reported a final preferred temperature of 32 C for YOY carp.

Ninespine Stickleback --

The ninespine stickleback (Pungitius pungitius) is a small, slender and compressed fish which attains a maximum length of about 64 mm (Scott and Crossman 1973). It principally inhabits the shores of larger lakes and coastal marine areas, residing in cool, quiet waters (Hubbs and Lagler 1964).

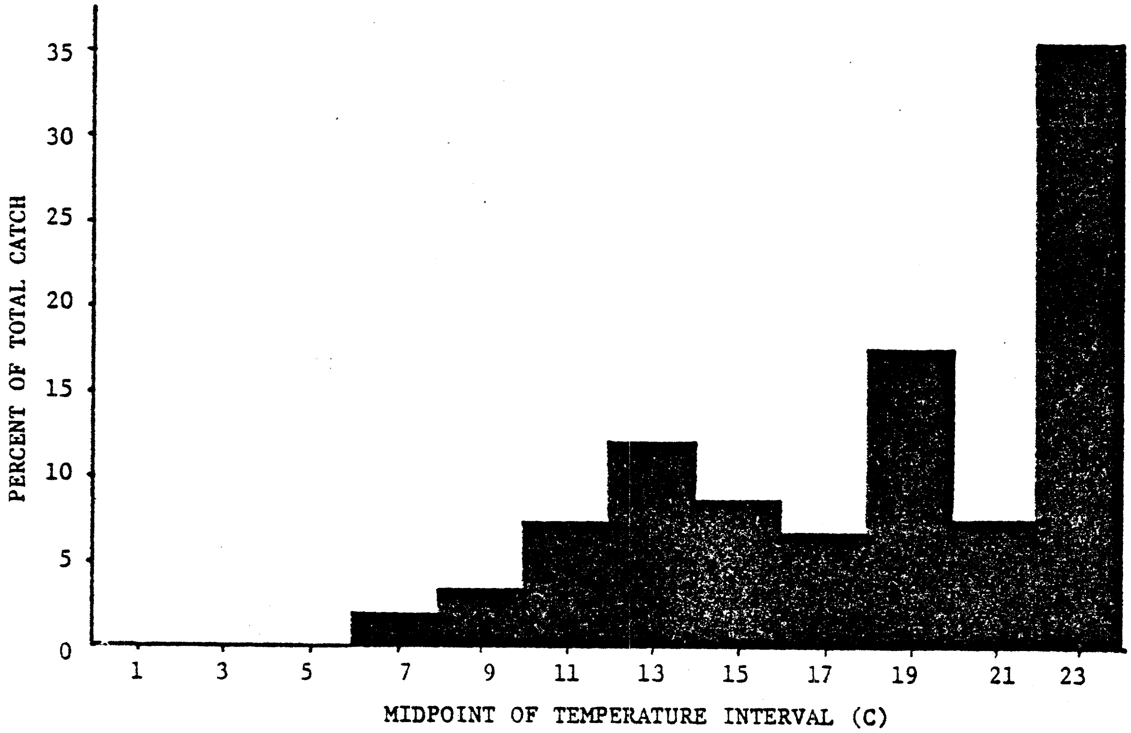

Fig. B89. Percentage of the total number of carp captured in all gear combined at given 2 C intervals in the Cook Plant vicinity, southeastern Lake Michigan, 1973-1974.

Sticklebacks were comparatively rare in Cook Plant study areas, accounting for only .02% (24 fish) of the total 1974 standard series catch. Sticklebacks were collected from March through June 1973 and April through August 1974. Only one stickleback was collected in both years prior to May, the month of maximum abundance. May catches accounted for 63% (12 fish) of the 1973 stickleback catch and 79% (15 fish) of the 1974 catch. Abundance of sticklebacks during May in Cook Plant study areas was thought to be in response to the warming of inshore waters and spring turnover. Griswold and Smith (1973) observed this phenomenon with sticklebacks in Lake Superior. They found sticklebacks to inhabit warmer deep water in early spring but as surface lake water warmed and spring turnover occurred sticklebacks began to disperse and were uniformly distributed at all depths. Griswold and Smith (1973) first collected sticklebacks inshore (5.5-16.5 m) in May, the same month in which they were collected in significant numbers at Cook Plant study areas. After May, however, numbers of stickleback collected at Cook declined sharply (Tables B6 and B9). Departure of sticklebacks from the inshore Cook Plant study areas after spring contrasts with Griswold and Smith (1973) who found that during midsummer sticklebacks were concentrated on warm, shallow shoals where water temperatures reached as high as 20 C.

Sticklebacks were collected in seines (eight fish in 1973, four fish in 1974) and trawls (11 fish in 1973, 20 fish in 1974) with most sticklebacks

being captured at night (18 of 19 in 1973, 17 of 24 in 1974), likely due to net avoidance during daylight. Daylight net avoidance was also observed by Griswold and Smith (1973) who found that sticklebacks were able to avoid shallow water (1-3.7 m) trawls during daylight.

Sticklebacks collected in the Cook Plant vicinity ranged in length from 60 to 78 mm (1.8-2.4 g) in 1973 and from 44 to 75 mm (1.0-2.8 g) in 1974. All individuals collected appeared to have been adults based upon comparisons of length ranges with average lengths per age-group reported by Griswold and Smith (1973). Age-groups 1-3 for males averaged 46.7, 60.2 and 65.6 mm while age-groups 1-5 for females averaged 47.5, 61.6, 68.5, 74.3 and 80.0 mm.

Comparing catch data between the Cook Plant and Warren Dunes for 1973 (13 fish at Cook and 8 at Warren Dunes) and 1974 (8 fish at Cook and 15 at Warren Dunes) revealed no demonstrable differences in catch size between areas. Similarly no differences were apparent between stations of equal depth. However, there was a difference between stations of different depth. All 9-m stations had consistently larger catches of sticklebacks than 6-m stations. Stickleback catches at seining stations were generally about the same size as at 6-m stations.

Maturation and spawning times of sticklebacks could not be determined with adequate precision from our data due to small sample size. However, a general time frame was determined from our data with the aid of the literature.

Gonad data for 1973-1974 showed sticklebacks were consistent in date of maturation when years were compared by month. Immature males and females and developing females were collected in February and March. Females with mature and developing gonads were first observed in April of each year and one spent female was caught in April 1974. Mature males were only observed in April. Only immature and males with well-developed gonads were observed in other months. Although our sample sizes after May were small (two to five fish per month) some fish with mature gonads were found in June and July.

The gonad development time frame observed in our data compares very well to that of Nelson (1967, 1968) for sticklebacks from Crooked Lake, Indiana. During both of his studies fully ripe eggs were found in females from April through August. Agreement is also close with the mid-June to late July spawning season reported by Griswold and Smith (1973).

No ripe-running sticklebacks of either sex were ever taken in the Cook Plant vicinity, nor was any stickleback spawning activity ever observed during monthly diving surveys (Dorr and Miller 1975). However, one 9.0-mm stickleback larva was collected in a surface net tow at beach station A (N Cook) in June 1974.

Due to our limited sampling regime and resulting data, little can be

said about the seasonal depth distribution of sticklebacks in the Cook Plant vicinity. Our data indicate a depth-oriented, seasonal migration for sticklebacks. The pattern of migration in Lake Michigan was similar to that reported by Griswold and Smith (1973) who found sticklebacks occupied warmer deep water in early spring (49-92 m in April and 18-92 m in May) and returned to deep water in early winter (49-92 m in November and December). Although mid-winter data were not available, Griswold and Smith felt that sticklebacks spent the winter in deep-water habitat because sticklebacks were abundant there the following spring. Spring and fall turnovers resulted in uniform distribution at all depths. By midsummer sticklebacks occupied shoal areas (1-4 m and 15-22 m).

In the Cook Plant vicinity sticklebacks moved inshore in early spring as expected. However they all but disappeared during summer months and by September sticklebacks were entirely absent. Where sticklebacks reside after leaving the Cook Plant vicinity is not known, however we feel that they likely moved further offshore.

Channel Catfish --

Standard series netting during 1974 accounted for 17 fish: 4 in gill nets, 10 in seines and 3 in trawls. Lengths ranged from 44 to 615 mm (0.9-2270 g); whereas, in 1973, 11 channel catfish ranging from 163 to 651 mm were caught. In 1974, five fish were collected during the day and 12 at night. Nine catfish were seined at Cook stations while only one was seined at Warren Dunes.

Gonad data for 1973 and 1974 followed the same pattern, spent fish appeared from June through September. This corresponds with the late spring to summer spawning season reported by Scott and Crossman (1973).

Another 20 channel catfish were impinged during 1974. Their sizes were slightly smaller (54-326 mm; 1.2-254 g) than most field-caught fish. Fish were impinged at low water temperatures, while all field-caught catfish were taken at higher temperatures from 7.6 to 22 C, with most captured at upper temperatures. Reasons for the increased impingement catch are probably due to the attractive influence of the intake structures and associated riprap, as well as the extremely low temperatures which would tend to reduce any attempts to fight against intake currents.

Northern Pike --

Northern pike were regularly collected in the Cook Plant vicinity during 1973-1974. They were collected in five of the 11 mo sampled in 1973, and in seven of the 11 mo sampled in 1974. Standard series fishing captured 16 pike in 1974 (nine during the day and seven at night), less than half the number (38 pike) collected in 1973. Gill nets were the most effective fishing gear taking 12 pike in 1974 (seven from 6-m stations and five from 9-m stations). The remaining four pike were collected in seines (three from the two Cook Plant stations, and one from Warren Dunes). No pike were trawled in 1974.

Pike collected in 1974 ranged in length from 214 to 644 mm (59.0-2000 g) with the majority 360-470 mm (about 2-3-yr old; Scott and Crossman 1973). Pike captured in 1973 exhibited a wider range of sizes (98-815 mm) with most fish 300 and 500 mm (about 2-4-yr old; Scott and Crossman 1973).

Gonad data pooled for 1973-1974 (Table B76) indicated that spawning occurred in March; two fish with well developed gonads were taken in the Cook Plant vicinity at this time. This agreed with the time reported by Machniak (1975), and Alt (1970) who stated that spawning commenced soon after ice left the spawning grounds. Spawning probably takes place in streams and lakes adjacent to Lake Michigan.

Table B76. Monthly gonad conditions of northern pike as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 and 1974 in southeastern Lake Michigan. All fish examined in a month were included except immatures.

Gonad Condition	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.	1	2	1	1	1		1	2	8	2	1
Mod. dev.									4		
Well dev.		2									
Ripe-running											
Spent			1	1							
					Males						
Poorly dev.			2	1	1			6	11		
Mod. dev.		2						3	3	1	
Well dev.											
Ripe-running											
Spent			1			1					
					Unable to distinguish						
				1				2			

Temperature catch data for northern pike were pooled for 1973-1974. Pike were taken at temperatures ranging from 0 to 25.9 C (Fig. B90). Maximum catch occurred when water was about 13 C, with a greater number of pike collected below 13 C.

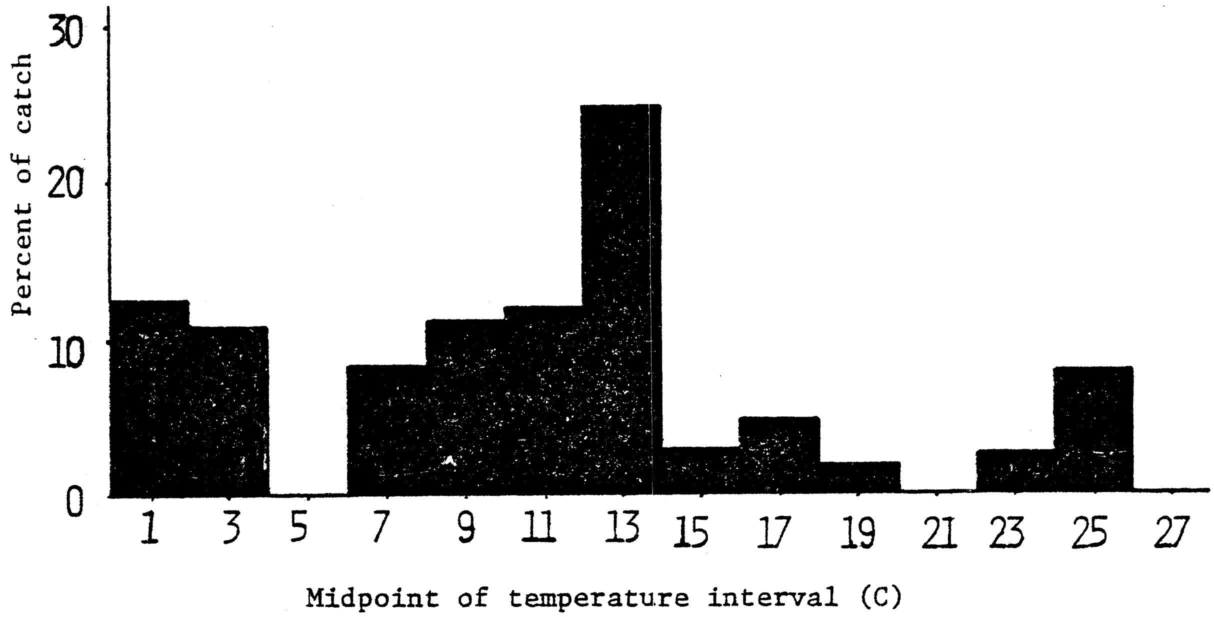

Fig. B90. Temperature-catch relationships of northern pike as shown by the percentage of the standard series catch occurring in each 2 C interval during 1973-1974. All gear catches were combined.

Burbot --

Fifteen burbot, 12 females and three males, were taken in 1974 standard series fishing (see Table B9), compared with six caught in 1973 (see Table B6). As in 1973, most were taken in gill nets--only one was trawled and none were seined which is probably because burbot are usually only present during cold-water months when no trawling was done. To some extent net avoidance may be the cause, since most burbot were large and probably able to outswim seines and trawls. Total length of burbot from 1974 standard series catches ranged from 285 to 593 mm (254-1600 g). This species was caught at all gill net stations (6 and 9 m, Cook and Warren Dunes) and was trawled at the Dunes at 9 m. Twelve of the 15 burbot were taken at night. Nine were collected at Cook and six at the Dunes; 11 were at 6 m, four at 9 m. Burbot in 1974 were captured in March, April, May, June and December in water 1.9-14.6 C. December specimens had ripe gonads. Those taken March-June had gonads that were either spent or relatively undeveloped. In 1973 ripe burbot were observed as late as April in the study area. Our data are in general agreement with Scott and Crossman (1973) who indicated that burbot spawned January-March in Canada and November-May elsewhere in their range.

Four ripe burbot (345-595 mm, 330-2040 g) were caught in supplementary gill nets during January at beach station A (three fish) and 21-m station E (one fish). Water temperature when these nets were set was 1 C. Two burbot were impinged in 1974, one in March and September.

Fish was the major food item eaten by burbot during 1973-1976. Burbot stomachs most frequently contained sculpins (slimy or mottled), but spottail shiners, alewives, ninespine sticklebacks, rainbow smelt, trout-perch, johnny darters and yellow perch were also found, as well as unidentified fish remains. These and other species eaten by burbot were cited by Lawler (1963) for Manitoba, McPhail and Lindsey (1970) for northwest Canada, McCrimmon and Devitt (1954) for Ontario, Van Oosten and Deason (1938) for Lake Michigan, Clemens (1951a) for Lake Erie and Bailey (1972) for Lake Superior. Data for Lake Michigan (Van Oosten and Deason 1938) also showed sculpins to be major food items, as we found.

While burbot are primarily inhabitants of hypolimnion waters in summer, Lawler (1963) and Scott and Crossman (1973), note that they will come intc "shallower" water to feed on summer nights. We have not seen them at this time, except for one taken in June at station C (S Cook 6-m), nor have we observed them inshore during upwellings when this cold-water species might be expected to come inshore as do adult smelt, lake trout and bloaters. Scarcity of this species in southern Lake Michigan, believed to be the result of lamprey predation and possibly of increasing eutrophication (Christie 1974, Smith 1972), could explain why we have not encountered this species in summer catches. In addition, the burbot is in the southern limit of its range here and inshore waters in the study area are usually too warm for it in summer.

Burbot are thought to spawn in shallow water, 3 m or less in depth (Scott and Crossman 1973, McPhail and Lindsey 1970, McCrimmon and Devitt 1954), though they may also spawn in much deeper water (Scott and Crossman 1973, Clemens 1951b).

Three burbot larvae appeared in April-May 1975 fish larvae tows, confirming the prediction by Jude et al. (1975), that the Cook plant area was used by burbot for spawning and that larvae would eventually be taken in larvae tows there. Larvae ranged in length from 4.0 to 4.5 mm and were taken during the day at station C (6 m), E (21 m) and W (21 m) off Warren Dunes. Larvae have also been found by other investigators both close to shore (McPhail and Lindsey 1970, Great Slave Lake, Canada and Lawler 1963, Manitoba) and in deep water (Fish 1932, Lake Erie). However, presence of only a few ripe adults (two of which were ripe-running) in our winter catches suggests that only a limited amount of spawning may occur in the plant vicinity.

Emerald Shiner --

Emerald shiners, once abundant in the Great Lakes have become scarce in recent years (Scott and Crossman 1973, Wells and McClain 1973). They were

caught occasionally in the area of the Cook Plant during 1973-1974. The decline of emerald shiners, based on reports from bait minnow dealers, was correlated with invasion of the alewife in Lake Michigan (Smith 1970 and S. H. Smith, personal communication, National Marine Fisheries Service, NOAA, Ann Arbor, Michigan). An actual relationship has not been documented, but we believe there is high probability of competition for food and space between larval emerald shiners and larval and adult alewives. Comparing our own studies of alewife abundance and distribution with literature on the emerald shiner (Flittner 1964) shows that both species are pelagic and both at times inhabit the inshore areas. Fish (1932) stated that emerald shiners were the only limnetic larvae in Lake Erie. Both species also breed in early summer and both feed on zooplankton throughout their lives. Flittner (1964) indicated that in Lake Erie the alewife competes strongly with the emerald shiner for food. It seems likely that since their appearance in Lake Michigan, alewives outcompeted emerald shiners and now dominate the inshore water column from spring through fall, while the emerald shiner population apparently collapsed. Low numbers of this species now present in the lake may represent strays from influent streams and lakes.

Emerald shiners decreased in abundance at the Cook Plant in 1974 compared to 1973. Only 13 (0.01% of the total catch) were caught in standard series sampling while 49 (0.03%) were caught in 1973 (see Tables B6 and B9). Large annual population fluctuations have been noted previously (Scott and Crossman 1973) and would not be unexpected in a species with the rapid reproduction, growth, and short life span (3 yr) which characterize emerald shiners (Fuchs 1967). Additionally, their occurrence in the inshore zone may be irregular, as they are essentially an open-water species (Scott and Crossman 1973).

Scott and Crossman (1973) also reported that schools of emerald shiners (mostly YOY) may come inshore in the autumn, an observation corroborated by our own data. All our specimens were collected by seine and were most abundant in the daytime in late summer or autumn, though they were present all year. It is probable when they enter the beach zone that they become vulnerable to our sampling gear; at other times this normally pelagic species may remain further offshore and perhaps closer to the surface than we would sample with trawl or gill net. Those individuals present in the beach zone apparently were feeding intensively as 40 out of 49 fish in 1973 and 12 out of 13 in 1974 were feeding.

Emerald shiners were more abundant at the Cook Plant than at Warren Dunes (56 at Cook, 6 at the Dunes). Most (39) were caught at station B (S Cook) in 1973, but in 1974 they were not distinctly more abundant at any one station. Station B was altered or disrupted both years; in 1973 by the safe harbor and in 1974 by dredging for the Lake Township, Berrien County water intake, so this station was neither a "normal" nor a consistent habitat.

Length distribution of emerald shiners in 1974 (range 45-94 mm, mean length 66 mm) did not change noticeably from that found in 1973. According to Fuchs' (1967) age and growth study, most of our specimens would be YOY

and age-group 1. Gonad data confirm this; 55% were immature. Sexual distinctions in adults were often difficult to make so sexual composition and seasonal condition of the gonads could not be determined. Fuchs (1967) however, reported a long spawning season, from June to August with the peak late July through August.

Temperature-catch data indicated a wide temperature tolerance with most caught at warmer temperatures. Emerald shiners were not impinged in 1973 or 1974. One was impinged in February 1975.

Rainbow Trout --

We made no distinction between the various forms of rainbow trout (e.g., steelhead trout, landlocked rainbow, etc). Only eight rainbow trout were captured in standard series fishing during 1974 (see Table B9); one in a gill net and four in seines during March, two in seines during April and one in a November seine. Four were captured during the day, four at night. Supplementary fishing captured an additional 25 fish, all in gill nets. Total 1974 (unadjusted) catch of rainbow trout was 33. Seined fish ranged from 125 to 285 mm (18.5-278 g); gillnetted fish from 371 to 770 mm (670-5780 g) (Table B77). In contrast to 1974, when eight fish were captured, 86 rainbows were caught in standard series fishing during 1973. The larger number of fish taken during 1973 were primarily from spring-summer seine catches. Seventy-two immature (132-268 mm) rainbows were seined April-August 1973; only two (125-229 mm) were seined during the same period in 1974. Indications are that only limited natural recruitment of salmonids is currently taking place in Lake Michigan, particularly in the southeastern section of the lake; extensive planting activities sustain Lake Michigan salmonid stocks at their present levels (Limnetics 1976). We suspect the variation between numbers of juvenile rainbow trout caught in 1973 and 1974 was related primarily to differences in local stocking rates and planting locations, although no obvious correlation was apparent. Additional field catch data are needed to explain inshore distribution and variation in populations of juvenile salmonids in southeastern Lake Michigan, and the process through which planting activities may influence or control distribution and variation.

During January and again during October-November, several adult fish were caught in gill nets set perpendicular to shore at beach station A (Table B77); only one fish was captured in standard series gill nets set parallel to shore at 6 and 9 m. These data support our 1973 observations that large rainbows, like brown trout and lake trout, travel the nearshore water close to shore during certain times of the year, usually October-March. Data from 1973 suggest juvenile rainbows utilized the beach zone (0-2 m) water, primarily during spring and summer, where they were particularly vulnerable to seining.

Gonad data (Table B78) indicated an extended fall and winter spawning period, beginning in October, terminating in May. This period was consistent with observations by Dodge and MacCrimmon (1970) that rainbow trout entered Bothwell's Creek (Lake Huron) to spawn in two distinct runs;

Table B77. Length-frequency distributions of rainbow trout caught during 1974 with seines and gill nets at five stations near the Cook Plant study areas, southeastern Lake Michigan.

Length Interval (mm)	Fishing Gear Seine	Gillnet	Station A	B	F	G	A[1]	1973 Standard Series	Sup.
<100									
100-149	3		2	1				11	
150-199								47	
200-249	3		1	1	1			20	
250-299	1			1				3	
300-349								1	1
350-399							1	1	1
400-449							3		
450-499							2		
500-549							1		6
550-599							4	1	6
600-649							4	11	5
650-699							4		2
700-749							4		1
750-799		1				1	2		
Totals	7	1	3	3	1	1	25	95	22

[1]Station A supplementary gillnetting north of Cook in beach zone

October 29-February 15 and February 16-May 3. Populations of both spring- and fall-spawning fish are planted in Lake Michigan (Daly et al. 1975), and our data may reflect the overlap of both spring and fall spawners, resulting in the extended period (November-May) over which well developed and ripe-running fish were taken. Spent fish were observed during November, March and May. Table B77 suggests two spawning peaks; one November-January and another in March. Immature fish were captured March-November, primarily during late spring and summer.

Table B78. Monthly gonad conditions of rainbow trout as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 and 1974 in southeastern Lake Michigan. All fish examined in a month were included.

Gonad Condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females							
Poorly dev.	1		1							1	2	
Mod. dev.												
Well dev.			5							3	1	
Ripe-running	2	1										
Spent			1		1							
					Males							
Poorly dev.				1								
Mod. dev.	3		1						1	5	1	2
Well dev.	1	1	4		1						2	
Ripe-running	5	1	1	1							1	1
Spent											2	
					Immature							
			4	16	30	11	4	11	1		4	
					Unable to distinguish							
						1	1			2		

Rainbow trout were captured over a wide range of water temperatures (0-25.9 C, Fig. B91). There was a tendency for smaller fish to be captured at higher water temperatures than large fish. Adults 280-770 mm were taken at water temperatures ranging from 3 to 11 C, juveniles 170-270 mm were caught at temperatures from 17 to 25 C and yearlings 110-160 mm at temperatures from 8 to 13 C.

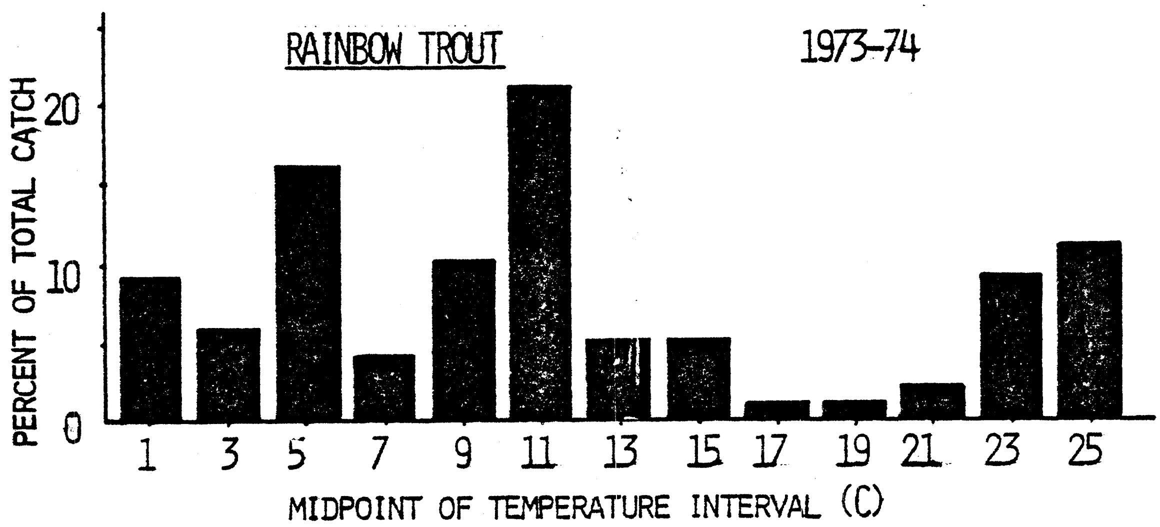

Fig. B91. Temperature-catch relationships of rainbow trout as shown by the percentage of the total catch occurring in each 2 C interval during 1973-1974 at Cook Plant study areas, southeastern Lake Michigan. All gear catches were combined. (N = 108 for 1973 and 33 for 1974).

Green Sunfish --

Green sunfish have occurred rarely in impingement and field collections. One was collected in an October seine haul in 1972. None were caught in 1973 but in 1974, one in June and two in July were impinged on the traveling screens and six individuals were seined, five in May at beach station F (Dunes) and one in October at station B (S Cook). These were all immature individuals ranging from 27 to 80 mm with a mean of 45 mm. Fourteen specimens were impinged in 1975. It seems likely that they may be attracted to riprap areas and underwater structures.

Sand Shiners --

Sand shiners were seined at the Cook Plant for the first time in 1974. Though rare, their absence from earlier collections may have been due to misidentification. Specimens collected in Ontario were generally found in sandy shallows of lakes and large rivers (Scott and Crossman 1973). In 1974 three specimens were seined in October; a 65-mm and a 74-mm shiner at beach station A (N Cook), and a 40-mm individual at station B (S Cook). In November a 65-mm specimen was seined at station B.

Black Bullhead --

Two black bullheads were seined during standard series fishing in both 1973 and 1974. In 1973 fish were caught at the south Cook beach station (B), one each in April and July. Six others were observed in impingement samples during April 1973. Lengths ranged from 87 to 140 mm (6.0-8.4 g).

In 1974 one fish each was seined during April and May at beach stations A and F respectively. Seven others were collected from impingement samples during six different months. Length range for the total sample was 86-201 mm (9.8-95.8 g). High impingement catches (when compared with field-caught fish) were attributed to the habitat created by riprap around the intake structure (see SECTION E).

Lake Whitefish --

Lake whitefish is the most distinct Great Lakes representative of a diversified European genus, _Coregonus_. Although still moderately abundant in many Canadian inland lakes, large populations no longer exist in Lake Michigan itself. Advances in net technology, environmental change, lamprey predation and extremely low survivability of several year classes were the more obvious agents in the decline of lake whitefish numbers.

After spawning in late fall, adult whitefish remain in shallow water until the following spring when warming water forces them to move deeper. Eggs hatch the following April or May. Newly-hatched larvae aggregate temporarily inshore before moving to deeper water in early summer (Scott and Crossman 1973).

In study year 1973, three small lake whitefish were taken. Two specimens were caught by standard series trawling in May and June at depths of 6 m and 9 m respectively. The third whitefish was taken during June by a supplementary gill net at station E (21 m). Fishing efforts in 1974 produced five lake whitefish (Table B79). Four were taken in supplementary deepwater gill net sets, and the fifth fish was caught in a night gill net set at station D (9 m).

Table B79. Biological data for lake whitefish caught during 1974 at Cook Plant study areas, southeastern Lake Michigan.

Sex	Length(mm)	Weight(g)	Date	Station	Diel Period	Bottom Temp(C)
Female	538	2320	3 Jan	E(21 m)	Night	1.0
Male	572	2420	16 Apr	4(12 m)	Day	6.2
Female	436	925	19 Aug	D(9 m)	Night	16.4
Female	430	863	23 Oct	E(21 m)	Night	12.7
Male	446	1150	23 Oct	E(21 m)	Night	12.7

The 1974 lake whitefish catch was comprised of healthy adult fish whose gonad condition corresponded well with the species' normal spawning schedule. Scale readings indicated the two largest fish were 7+ yr old while smaller fish were evidently 3 to 4-yr old.

Ice and heavy weather prevent the gillnetting and trawling required to sample the population during their inshore winter stay. In effect, sampling efforts are reaching only early arrivals and holdovers from the winter onshore movement. Consequently, a cross section of the population age-class structure is not readily available.

Golden Shiner --

Golden shiners prefer quiet lakes with an abundance of vegetation (Scott and Crossman 1973) and are only rarely caught in the vicinity of the Cook Plant. In 1973 one individual was seined at Warren Dunes and one north of the Cook Plant in April. In 1974 a 61-mm specimen was collected in an August seine haul at station A (N Cook). This species did not occur in traveling screen collections until 1975 when four individuals were impinged in March and April.

Largemouth Bass --

As in 1973, only one largemouth bass (92 mm, 7.8 g) was captured in standard series sampling, again at beach station B (S Cook). The 1974 catch was from a day seine in June when water temperature was 18.2 C. Pertinent age/size class data are as follows: Beckman (1949) for Michigan, (0)-84 mm, 7.9 g, (1)-155 mm, 65.2 g; Mackay (1963) for Ontario, (1)-170 mm, 65.2 g. Taking these data into account along with a known late spring through August spawning season (Scott and Crossman 1973) the fish we caught was probably 1-yr old.

Lake Herring --

The lake herring, _Coregonus artedii_, lies at the center of a large taxonomic puzzle. Intraspecific variation is more predominant among _C. artedii_ than any other cisco species found in the Great Lakes. Young _artedii_ are difficult to distinguish from the bloater, (_C. hoyi_) and kiyi (_C. kiyi_), which is thought to be extinct in Lake Michigan. Lake Michigan still supports a large population of _C. hoyi_. To complicate matters further, both _C. hoyi_ and _C. artedii_ have undergone a large amount of morphometric change in the past two decades.

The majority of small coregonids in the 1974 study were classified as unidentified. It is probably correct to assume that a large proportion of unidentified fish were _C. hoyi_; however, the possibility of intermittent _C. artedii_ should not be overlooked.

A single large female lake herring was taken in a gill net at station E (21 m) in February 1973. In 1974 another large female _C. artedi_ (452 mm, 960 g) was caught. The fish was taken at station C (6 m) by a day gill net set on 20 December. The spent condition of the fish coincided well with the

early winter spawning period of the species. A continued discussion of the lake herring's role in the coregonid problem may be found in the section on unidentified coregonids.

Bluntnose Minnow --

Bluntnose minnows prefer a rock or gravel-bottom lake or stream and individuals collected in the vicinity of the Cook Plant are undoubtedly strays. Only one individual has been collected in this area, a 56-mm immature specimen seined at station B (S Cook) in October 1974.

Central Mudminnow --

Mudminnows have been collected from the traveling screens but have not yet been caught during standard series sampling. In 1973 two specimens were impinged; one 82-mm individual in March, the other a 79-mm specimen in April. In 1974, 32 specimens were impinged, 22 of them in March. Lengths ranged from 62 to 94 mm, with a mean of 79 mm.

As this species usually inhabits ponds or pools with an abundance of vegetation and organic material (Scott and Crossman 1973), the Cook Plant study area offers a very uncharacteristic environment. Occurrence of this species exclusively in impingement catches suggests that it may have been attracted to the _Cladophora_ and riprap around the intake structures, possibly for spawning.

Although March was the month of maximum abundance of mudminnows, it may be early for spawning, which occurred in April in New York and Ontario when water temperatures were about 13 C (Scott and Crossman 1973). Water temperatures at the Cook Plant in March and April were substantially lower, 4.4-9.0 C. Females had well-developed gonads, but male gonads were only moderately developed.

Peak abundance of mudminnows in March 1974 impingement catches may be related to plant intake water pumping, which was first conducted extensively during this month. Prior to this time a small population may have become established on the riprap. Only nine mudminnows (all impinged) were collected in 1975.

Quillback --

In 1974 quillbacks continued to be infrequent in our catches. Five were taken in 1974, compared with two caught in 1973. Four of the 1974 quillbacks were adult females ranging between 420 and 477 mm and weighing 1220 to 1610 g. All four were taken north of the plant at station A in supplementary day gill nets set at depths of 1.5 to 3 m. Two females caught in June had already spawned. The other two, captured in August, had gonads which were moderately developed, but not ripe. These observations agree with those of Scott and Crossman (1973) and Mansueti and Hardy (1967), who reported that quillbacks spawned in April and May.

One small quillback, presumably a YOY (77 mm, 6.2 g) was taken in December impingement sampling. Trautman (1957) noted that November

quillback YOY ranged from 51 to 127 mm in Ohio. An Iowa study indicated that YOY in July and August were under 51 mm and that average length for a yearling was 122 mm (Vanicek 1961).

Rock Bass --

Four rock bass were caught in 1974. One (205 mm, 180.4 g) was captured in a supplementary March day gill net set at station A (N Cook). Gonads of this fish were developing but not yet ripe.

The other three rock bass were from daytime impingement catches, two in February and one in June. The impinged fish were 36-55 mm and weighed 0.4-3.0 g. Trautman (1957) gave the following rock bass age/size class data for Ohio: YOY (in October), 20-51 mm and yearlings, 28-89 mm. According to Beckman (1949), Michigan YOY averaged 38 mm and 1.1 g; means for yearlings were 81 mm and 11.9 g. These data and the late spring-early summer spawning season of the species (Scott and Crossman 1973) suggest that the three impinged fish were spawned in 1973. Rock bass were also rare in 1973 catches as only two were taken.

Lake Sturgeon --

Lake sturgeon, now rare and threatened in Lake Michigan, were not killed if observed alive in nets. Therefore live individuals were measured and released at the station of capture. As a result complete data (length, weight, gonad development and stomach contents) are available on only two of the three fish taken in 1974 (two were captured in 1973).

The three fish in 1974 were captured exclusively with gill nets. One was 625 mm, taken at station C (6 m-S Cook), one was 622 mm (1525 g) taken at the beach station north of Cook (station A) and the last was 623 mm (1350 g) captured at station E (21 m). The individuals from stations A and E were immature males. Fish captured during both years were taken in supplementary gill nets.

Pumpkinseed --

Pumpkinseed sunfish are usually found in small lakes or embayments with submerged vegetation or brush (Scott and Crossman 1973). This species has never been taken in standard series sampling at the Cook Plant but occurs rarely in impingement catches. Individuals which stray into the area may be attracted to the riprap with the accompanying growth of Cladophora around the intake structure. Pumpkinseeds impinged at the plant include a 97-mm individual from January 1973, a 60-mm specimen from June 1974 and seven pumpkinseeds which have been impinged through November 1975.

Fathead Minnow --

Typically inhabiting rivers, ponds and small lakes, fathead minnows caught at the Cook Plant are probably strays. There is no evidence of an established population in this area. In 1973, two immature fish were caught in seines at station A (N Cook), one in May and one in July. None were collected in standard series sampling in 1974; however, one 47-mm immature individual was impinged in June. None have been impinged through November 1975.

Smallmouth Bass --

One adult male smallmouth bass 275 mm and 383 g was caught in a supplementary night gill net at station A (N Cook). In July 1975 adults were twice observed swimming above the riprap around the discharge structures by SCUBA divers. Though not normally inhabiting the area, occasional transients may be attracted to the rocky substrate of the riprap.

SECTION C

SPATIAL AND TEMPORAL DISTRIBUTION OF FISH LARVAE AND EGGS DURING 1973-1974 IN THE INSHORE WATERS OF SOUTHEASTERN LAKE MICHIGAN

INTRODUCTION

Of paramount importance in understanding any organism is thorough knowledge of the behavior, distribution and growth of individuals in the population. Mortality of fish eggs and larvae in part determines the number of adult fish that are ultimately produced. It is thus vital to establish with relative confidence the temporal behavior, spatial distribution and abundance of fish larvae present in a water body. From these data, one can then evaluate the impact of a given vector of mortality on larval populations. For example, our data on seasonal succession of fish larvae near the Cook Plant will assist in siting any future building or development along this part of the Lake Michigan coastline by providing critical information for minimizing impacts on larval fish populations.

Our primary objective was to provide the necessary preoperational data from which effects due to thermal input and intake entrainment can be judged. This section will be a detailed analysis of the preoperational 1973-1974 fish larvae and egg data. Since the Cook plant became operational during 1975, the previous 2 yr of data will be used to detect any changes in numbers or species composition which may occur as a result of Cook Plant operation. These data will address the occurrence and density of larvae in the Cook Plant and Warren Dunes areas for differences with season, diel period and depth.

Our sampling scheme was biased since pelagic eggs and larvae were collected more efficiently than demersal larvae or eggs because plankton nets only sampled within 0.5-1 m of the bottom. The only way demersal larvae and eggs may have been collected was incidently because of currents or wave action stirring eggs and larvae (both dead and alive) from the bottom. To assist in answering questions about what larvae and eggs were present on the bottom, tows with a fish larvae sled were also made.

Lastly, since analysis of fish larvae data is only as sound as the taxonomic determinations for each specimen, we have included a section summarizing our knowledge of the salient characters used to distinguish species. Included are key characters, line drawings and methods for separating larvae based on known spawning times of adults.

METHODS

Fish Larvae

A conical, 0.5-m diameter, nylon plankton net of no. 2 mesh (363-micron

aperature) was used to collect fish larvae, arbitrarily defined as any fish less than 2.54 cm total length. A hydrodynamic depressor was used for all open water tows. During 1973, samples from all seven standard series stations (A, B, F, C, D, G, H -- Fig. B1) were collected day and night once per month from April to November. Data on exact times, weather conditions and secchi disc readings at the time plankton net and sled tow samples were collected are given in Table C1A.

Four 5-min tows parallel to shore were conducted during 1973 using the R/V Mysis at an average speed of 3-6 km/h at each deepwater station (C, D, G, H). These tows consisted of one 5-min tow each at 0, 1 and 2 m, and a single steptow at deeper levels, as follows: 100 s each at 3, 4 and 5 m for 6-m stations; 100 s each at 4, 6 and 8 m for 9-m stations; and 100 s each at 7, 13 and 19 m for the 21-m station (E). Length of cable released to obtain a desired tow depth was obtained by calculation using trigonometry; wire angle averaged about 25 degrees. For beach stations A, B and F during 1973 a set of duplicate surface tow samples was obtained by towing the net held just under the water surface by hand north to south, then south to north, a distance of 31 m (100 ft) once during the day and once at night at a depth of approximately 1 m. In 1974 this procedure was changed slightly so that duplicate tows were conducted simultaneously against the current for a distance of 61 m (200 ft). All samples were immediately preserved in a 10% formaldehyde solution. Some indication of the effect of preservation on length measurements of larvae can be obtained from Sameoto (1971) who found for herring larvae collected in Nova Scotia and preserved with 5% formaldehyde in seawater for 1 mo that only a 3.8% decrease in weight occurred (range in weight of fresh larvae was 11-63 mg). Toetz (1966) measuring bluegill larvae lengths before and after preservation in formaldehyde found larvae had also shrunk only 3.8%.

In 1974, the open water towing procedure was also changed so that discrete tows were performed at every 2 m of depth for 6- and 9-m stations (C, D, G, H) eliminating the step tow. Tows were done day and night once per month from April to November, weather permitting. For 6-m stations a 5-min, horizontal tow was done at 0.5, 2, 4 and 5.5 m; for 9-m stations similar tows were done at 0.5, 2.5, 4.5, 6.5 and 8.5 m and for the 21.4-m station tows were done at 0.5, 7.5, 13.5 and 20 m. As in 1973, reduced sampling was done at station E (21 m off Cook) when time permitted.

A Rigosha flowmeter (Model No. 2536-A, Rigosha and Company Limited, 10-4 Kajicho 1-Chome, Chiyoda-Ku, Tokyo, 101 Japan) rigidly fixed to the center opening of the net measured volume of water sampled. Flowmeters were calibrated by four people pulling a 0.5-m diameter ring horizontally with and without the net 13.3 m four times each in an indoor swimming pool. Efficiencies (ratio of volume of water filtered with the net to volume of water filtered without the net) were calculated to be 84 and 92% for the two meters and nets used in 1973. Each revolution of the flowmeter during 1973 was calculated to represent 0.0170 m^3 or 17.0 liters of water filtered by the net. In 1974, more extensive calibrations in the pool resulted in one revolution of the flowmeter equalling 15 liters which was used for 1974

Table C1A. Date (month-day), time (EST) and some physical and limnological parameters measured during fish larvae tows, including surface, midwater and sled tows, 1974.

Starting date	Starting time	Station	Temp C Surface	Temp C Bottom	Wind Dir. from	Wind Speed mph	Waves Dir. from	Waves Height (m)	Weather
1-29	1310	A	0.4	0.4	S	5-10	SW	.6	overcast
1-29	1415	B	0.4	0.4	S	5-10	SW	.6	overcast
3-15	1020	A	4.8	4.1	S	5-10	S	0-.2	-
3-06	2215	A	6.2	6.2	W	0-5	SW	.2	cloudy
3-15	0850	B	3.8	3.8	S	5-10	S	0-.2	-
3-06	2045	B	6.2	6.2	W	0-5	SW	.2	cloudy
3-15	0745	F	3.5	3.7	SE	10	calm		cloudy, fog
3-14	2005	F	4.2	4.2	S	5	calm		-
4-03	1700	A	10.2	10.2	SE	20-25	var.	.1-.2	rain
4-09	1710	A	5.5	5.5	W	0-5	W	.3	overcast
4-18	1415	A	12.0	12.0	W	5-10	N	.3	sunny & haze
4-19	0115	A	7.4	7.3	NE	0-5	calm		clear
4-24	1530	A	11.0	11.0	NW	5-10	NW	.9-1.2	clear
4-03	1800	B	10.2	10.2	SE	20-25	SE	.1-.2	rain
4-09	1745	B	5.5	5.5	W	0-5	W	.3	overcast
4-18	1305	B	11.5	11.3	W	5-10	N	.3	sunny & haze
4-19	0035	B	7.1	7.1	NE	0-5	calm		clear
4-18	1145	F	12.0	11.3	W	5-10	N	.3	sunny & haze
4-19	2220	F	8.2	8.2	NE	0-5	calm		clear
4-17	1850	C*	-	-	S	0-5	calm		clear
4-17	1207	C	8.6	7.7	SW	5-10	SW	.3	sunny & haze
4-17	0033	C	7.2	6.4	calm		calm		clear
4-17	2015	D*	-	-	S	0-5	calm		clear
4-17	1413	D	9.2	8.0	SW	5-10	SW	.3	sunny & haze
4-16	2320	D	7.3	6.0	S	0-5	calm		clear
4-16	1503	G	8.8	7.4	calm		NW	.3	clear
4-16	2015	G	8.0	7.6	calm		NW	0-.2	clear
4-16	1625	H	7.0	7.0	NW	0-5	NW	.3	clear
4-16	2130	H	7.9	6.4	calm		calm		clear
4-17	1026	N*	-	-	S	0-5	calm		clear
4-17	1748	P*	8.0	8.0	S	0-5	calm		clear
5-02	2238	A	11.0	11.0	SE	0-5	calm		rain
5-03	1305	A	11.5	11.5	NW	10-15	NW	.9	rain
5-08	1800	A	9.2	9.2	NE	5-10	NE	.6	rain
5-09	1930	A	8.0	8.0	N	0-5	NW	.3	overcast
5-16	0055	A	11.1	11.1	N	0-5	calm		clear
5-17	1415	A	12.7	12.5	NE	0-5	N	.6	overcast & haze
5-22	1210	A	12.0	12.0	SW	5-10	SW	.2	overcast & haze
5-02	2203	B	13.0	13.0	SE	0-5	calm		rain
5-03	1240	B	10.5	10.5	NW	10-15	NW	.9	rain
5-08	1815	B	9.2	9.2	NE	5-10	NE	.6	rain
5-09	1950	B	8.0	8.0	N	0-5	NW	.3	overcast
5-14	2345	B	12.5	12.4	N	0-5	calm		clear
5-17	1330	B	12.1	12.1	N	5-10	N	.6	overcast & haze
5-22	1300	B	12.0	12.0	SW	5-10	SW	.2	overcast & haze
5-02	2100	F	11.0	10.5	SE	0-5	calm		rain
5-03	1145	F	9.5	9.5	NW	10-15	NW	.9	rain
5-15	2205	F	11.9	11.9	var.	0-5	calm		clear
5-17	1215	F	12.7	12.5	N	5-10	NW	.6	overcast & haze
5-08	1710	C*	9.2	9.2	NE	5-10	NE	.3	rain
5-13	1650	C*	9.0	9.0	E	5-10	NW	.2	overcast
5-13	1637	C	9.5	9.1	SE	5-10	SE	.2	pt. cloudy
5-14	0025	C	9.2	8.8	SE	15-20	SE	-	pt. cloudy
5-08	1700	D*	9.2	9.2	NE	5-10	NE	.3	rain
5-13	1735	D*	9.0	9.0	E	5-10	NW	.2	overcast
5-13	1508	D	9.2	9.0	SE	10-15	SE	.3-.6	rain
5-13	2307	D	9.3	8.4	SE	15-20	SE	.3-.6	pt. cloudy
5-14	1228	G	10.5	10.1	SW	5-10	SW	.6	pt. cloudy
5-13	2135	G	9.8	9.3	E	5-10	SE	.3	pt. cloudy
5-14	1120	H	10.0	9.9	SW	10-15	S	.6	pt. cloudy
5-13	2020	H	9.5	8.9	E	5-10	SE	.3	pt. cloudy
5-08	1725	N*	9.2	9.2	NE	5-10	NE	.3	rain
5-13	1725	N*	10.2	10.0	E	5-10	NW	.2	overcast
5-08	1740	P*	9.2	9.2	NE	5-10	NE	.3	rain
5-13	1735	P*	9.4	9.4	E	5-10	NW	.2	overcast
6-01	1345	A*	18.2	18.2	N	5-10	NW	.5	pt. cloudy

Table C1A. Continued.

Starting date	Starting time	Station	Temp C Surface	Temp C Bottom	Wind Dir. from	Wind Speed mph	Waves Dir. from	Waves Height (m)	Weather
6-01	1430	A	18.2	18.2	N	10-15	N	.3	pt. cloudy
6-05	0030	A	18.5	18.5	S	0-5	calm		clear
6-05	1402	A	18.5	18.5	S	5-10	SW	.3	rain
6-11	1755	A*	16.8	16.8	SW	0-5	SW	.3	rain
6-11	1739	A*	16.8	16.8	calm		W	.6	clear
6-11	2305	A	18.2	18.2	SW	0-5	S	.1	pt. cloudy
6-25	2253	A	13.1	13.1	NE	5-10	NW	.9	clear
6-26	1522	A	17.0	17.0	NE	5-10	NW	.6	clear
6-01	1335	B*	18.8	18.8	N	5-10	NW	.5	pt. cloudy
6-01	1510	B	18.8	18.8	N	10-15	-	.3	pt. cloudy
6-04	2255	B	18.0	18.0	E	0-5	calm		clear
6-05	1256	B	18.5	18.2	S	5-10	SW	.2-.3	rain
6-11	1157	B*	16.5	16.5	SW	0-5	SW	.3	rain
6-11	1703	B	16.5	16.5	calm		W	.6	clear
6-12	2140	B	18.0	18.0	SW	0-5	S	.1	pt. cloudy
6-25	2223	B	13.1	13.1	NE	0-5	NW	.8	clear
6-26	1427	B	17.5	17.3	NE	5-10	NW	.3-.5	clear
6-01	1630	F*	18.6	18.6	N	5-10	NW	.5	pt. cloudy
6-01	1705	F	18.6	18.6	N	10-15	NW	.3	pt. cloudy
6-04	2115	F	17.5	17.5	E	5-10	calm		clear
6-05	1143	F	17.5	18.0	SE	5-10	SW	.2	overcast
6-11	1600	F*	17.5	17.5	SW	0-5	SW	.3	rain
6-11	1605	F	17.5	17.5	SW	0-5	SW	.3	rain
6-12	2230	F	18.0	18.0	SW	0-5	S	.1	pt. cloudy
6-25	2110	F	15.2	15.1	NW	5-10	NW	.9	pt. cloudy & haze
6-26	1134	F	16.3	16.0	NW	5-10	NW	.3-.6	sunny & haze
6-01	1910	C*	13.1	13.1	N	5-10	NW	.3	clear
6-11	1839	C*	14.7	14.2	SW	0-5	SW	.3	clear
6-12	2232	C*	15.4	15.5	SW	0-5	calm		pt. cloudy
6-12	1517	C	17.6	16.4	SW	0-5	W	.2	sunny & haze
6-12	0020	C	14.2	14.2	SW	10-15	SW	.3	clear
6-20	1742	C*	18.0	16.2	SE	-	S	.2	sunny & haze
6-26	2242	C*	14.0	13.0	NE	0-5	NW	.2	clear
6-26	2028	C*	14.9	15.0	NE	5-10	NW	.3-.6	clear
6-01	1855	D*	14.2	14.2	N	5-10	NW	.3	clear
6-11	1918	D*	14.5	14.2	SW	0-5	SW	.3	rain
6-12	2245	D*	15.2	14.5	SW	0-5	calm		pt. cloudy
6-12	1355	D	17.0	15.0	SW	0-5	W	.2	clear
6-12	0005	D	14.1	14.2	SW	5-10	SW	.3	-
6-20	1755	D*	18.9	15.2	SE	-	S	.2	sunny & haze
6-26	2155	D*	13.5	12.5	NE	0-5	NW	.3	clear
6-26	2038	D*	14.9	15.0	NE	5-10	NW	.3-.6	clear
6-12	1615	E	15.5	12.8	SW	0-5	W	.2	pt. cloudy & haze
6-11	1713	G	15.3	15.0	calm		W	.3-.6	clear
6-11	2056	G	14.0	14.5	W	5-10	W	.2	pt. cloudy
6-11	1602	H	14.5	15.0	W	10-15	W	.3-.6	rain
6-11	2231	H	13.8	14.3	SW	0-5	W	.2	pt. cloudy
6-01	1920	N*	13.1	13.1	N	5-10	NW	.3	clear
6-11	1955	N*	15.0	14.7	SW	0-5	SW	.3	clear
6-12	2226	N*	16.0	15.6	SW	0-5	SW	calm	pt. cloudy
6-20	1728	N*	19.5	17.0	SE	0-5	S	.2	sunny & haze
6-26	2124	N*	13.0	13.0	NE	0-5	NW	.3	clear
6-26	2017	N*	14.9	15.0	NE	0-5	NW	.3	clear
7-08	1645	A*	25.0	23.3	NE	0-5	calm		sunny & haze
7-08	1800	A	25.5	23.5	calm		calm		sunny & haze
7-11	0115	A	20.4	20.2	NE	0-5	NE	.3	overcast
7-24	1150	A	16.2	15.0	N	0-5	W	.2	clear
7-11	0205	A*	20.4	20.2	NE	0-5	NE	.3	overcast
7-24	1200	A*	16.2	15.0	NW	0-5	W	.2	clear
7-17	1510	A*	22.5	22.0	SW	0-5	calm		clear
7-17	1530	A	22.5	22.0	SW	0-5	calm		clear
7-17	1424	A*	22.0	22.0	SW	0-5	calm		clear
7-16	2312	A*	18.5	18.5	E	0-5	calm		-
7-16	2325	A	18.5	18.5	E	0-5	calm		-
7-22	2315	A*	16.0	16.0	NE	0-5	SW	.3	-
7-22	2315	A	16.0	16.0	NE	0-5	SW	.3	-

Table C1A. Continued.

Starting date	Starting time	Station	Temp C Surface	Temp C Bottom	Wind Dir. from	Wind Speed mph	Waves Dir. from	Waves Height (m)	Weather
7-08	1900	B*	22.5	24.5	NE	0-5	calm		clear
7-11	0135	B*	20.0	19.9	NE	0-5	NE	.3	overcast
7-24	1245	B*	16.9	16.9	NW	0-5	W	.2	clear
7-08	1900	B	24.0	22.5	calm		calm		clear
7-11	0045	B	21.0	19.9	NE	0-5	NE	.3	overcast
7-24	1235	B	16.9	16.9	N	0-5	W	.2	clear
7-16	2250	B	18.5	18.5	E	0-5	calm		clear
7-16	2235	B*	18.5	18.5	E	0-5	calm		clear
7-17	1430	B	22.0	22.0	SW	0-5	calm		clear
7-22	2240	B*	15.9	15.9	NE	0-5	SW	.3	-
7-22	2250	B	15.9	15.9	NE	0-5	SW	.3	-
7-08	1614	F*	24.0	22.5	NE	0-5	calm		clear
7-11	0035	F*	21.1	21.1	NE	0-5	NE	.3	overcast
7-24	1120	F*	18.0	18.0	NW	0-5	W	.2	clear
7-08	1625	F	24.0	22.5	calm		calm		sunny & haze
7-10	2345	F	21.1	21.1	NE	0-5	NE	.3	overcast
7-24	1110	F	18.0	18.0	N	0-5	W	.2	clear
7-22	2135	F	16.1	16.1	E	0-5	SW	.3	overcast & fog
7-22	2145	F*	16.1	16.1	E	0-5	SW	.3	overcast & fog
7-17	1244	F*	20.2	20.2	SE	0-5	SE	.2	sunny & haze
7-17	1250	F	20.2	20.2	SE	0-5	SE	.2	sunny & haze
7-16	0001	F*	19.0	19.0	E	0-5	calm		clear
7-16	0008	F	19.0	19.0	E	0-5	calm		clear
7-09	1500	C*	23.3	17.3	S	0-5	calm		sunny & haze
7-10	2145	C*	19.0	17.0	NE	0-5	N	.2	overcast
7-16	1953	C*	18.3	15.2	NE	0-5	calm		sunny & haze
7-16	2147	C*	18.2	15.5	NE	0-5	calm		-
7-24	1535	C*	17.8	12.6	NE	0-5	calm		sunny & haze
7-24	2200	C*	17.3	15.0	var.	0-5	calm		clear
7-09	1430	C	25.0	19.9	calm		calm		sunny & haze
7-09	0018	C	21.8	15.0	S	15-20	N	.3	overcast & haze
7-16	2006	D*	18.7	14.4	NE	0-5	calm		sunny & haze
7-10	2130	D*	19.5	14.5	NE	0-5	N	.2	overcast
7-09	1530	D*	25.9	17.0	S	0-5	calm		sunny & haze
7-16	2303	D*	18.2	11.7	NE	0-5	calm		-
7-24	1550	D*	17.3	12.0	NE	0-5	calm		sunny & haze
7-24	2210	D*	17.8	13.7	var.	0-5	calm		clear
7-09	1227	D	23.6	11.3	S	0-5	calm		sunny & haze
7-08	2359	D	21.2	10.2	S	0-5	calm		overcast & haze
7-09	1520	E	22.0	8.2	calm		calm		clear
7-08	1616	G	24.4	17.6	S	0-5	calm		sunny & haze
7-08	2224	G	21.5	11.3	SE	5-10	calm		overcast & haze
7-08	1356	H	23.7	14.8	calm		calm		sunny & haze
7-08	2105	H	24.0	10.5	SW	0-5	N	.2	overcast & haze
7-16	1930	N*	18.9	16.2	NE	0-5	calm		sunny & haze
7-09	1545	N*	25.0	20.8	S	0-5	calm		clear
7-10	2200	N*	19.0	18.0	NE	0-5	N	.2	overcast
7-16	2136	N*	18.5	17.2	NE	0-5	calm		-
7-24	1520	N*	17.3	15.3	NE	0-5	calm		sunny & haze
7-24	2145	N*	17.2	15.9	var.	0-5	calm		clear
7-09	1430	P*	25.5	24.0	S	0-5	calm		clear
7-10	2200	P*	19.2	19.0	NE	0-5	N	.2	overcast
7-16	1918	P*	19.5	17.5	NE	0-5	calm		sunny & haze
7-16	2124	P*	18.5	16.7	NE	0-5	calm		-
7-24	1507	P*	18.9	17.1	NE	0-5	calm		sunny & haze
7-24	2130	P*	17.6	16.7	var.	0-5	calm		clear
8-05	0145	A	19.4	19.2	E	0-5	NW	.2	pt. cloudy
8-05	0145	A*	19.4	19.2	E	0-5	NW	.2	pt. cloudy
8-06	1415	A	22.7	22.5	NW	0-5	NW	.3	overcast & haze
8-06	1415	A*	22.7	22.5	NW	0-5	NW	.3	overcast & haze
8-14	1243	A	18.5	18.3	NE	0-5	NW	.3-.5	clear
8-14	1243	A*	18.5	18.3	NE	0-5	NW	.3-.5	clear
8-14	2220	A	17.7	17.7	NE	0-5	NW	.3	clear
8-14	2220	A*	17.7	17.7	NE	0-5	NW	.3	clear
8-19	1717	A	24.0	24.0	calm		calm		sunny & haze

Table C1A. Continued.

Starting date	Starting time	Station	Temp C Surface	Temp C Bottom	Wind Dir. from	Wind Speed mph	Waves Dir. from	Waves Height (m)	Weather
8-19	1725	A*	24.0	24.0	calm		calm		sunny & haze
8-19	2240	A	22.0	22.0	SE	0-5	calm		clear
8-19	2250	A*	22.0	22.0	SE	0-5	calm		clear
8-05	0110	B	19.7	19.5	E	0-5	NW	.2	pt. cloudy
8-05	0110	B*	19.7	19.5	E	0-5	NW	.2	pt. cloudy
8-06	1314	B	22.2	22.1	NW	0-5	NW	.2-.3	overcast & haze
8-06	1338	B*	22.2	22.1	NW	0-5	NW	.2-.3	overcast & haze
8-14	1045	B	19.4	19.0	NE	5-10	NW	.5-.6	clear
8-14	1055	B*	19.4	19.0	NE	5-10	NW	.5-.6	clear
8-14	2140	B	17.0	16.8	NE	0-5	NW	.3	clear
8-14	2145	B*	17.0	16.8	NE	0-5	NW	.3	clear
8-19	1657	B	24.0	24.0	calm		calm		sunny & haze
8-19	1708	B*	24.0	24.0	calm		calm		sunny & haze
8-19	2105	B	22.0	22.0	SE	0-5	calm		clear
8-19	2120	B*	22.0	22.0	SE	0-5	calm		clear
8-05	0300	F	20.3	20.1	E	0-5	NW	.2	pt. cloudy
8-05	0310	F*	20.3	20.1	E	0-5	NW	.2	pt. cloudy
8-06	1525	F	23.5	22.8	NW	0-5	NW	.3	clear
8-06	1540	F*	23.5	22.8	NW	0-5	NW	.3	clear
8-14	0925	F	19.0	18.5	NE	5-10	NW	.5-.6	clear
8-14	0917	F*	19.0	18.5	NE	5-10	NW	.5-.6	clear
8-14	2340	F	14.5	14.1	NE	0-5	NW	.3	clear
8-14	2331	F*	14.5	14.1	NE	0-5	NW	.3	clear
8-19	1744	F	23.0	23.0	calm		calm		sunny & haze
8-19	1750	F*	23.0	23.0	calm		calm		sunny & haze
8-19	2215	F	21.0	21.0	S	0-5	SW	.2	-
8-19	2200	F*	21.0	21.0	S	0-5	SW	.2	-
8-04	2337	C*	20.5	20.0	E	0-5	calm		-
8-20	1427	C	24.0	22.5	calm		calm		sunny & haze
8-19	2400	C	20.5	19.5	NE	5-10	calm		clear
8-07	1530	C*	21.3	21.0	N	5-10	NW	.3	sunny & haze
8-08	1614	C*	23.0	-	calm		calm		sunny & haze
8-20	2147	C*	21.5	20.5	SE	0-5	calm		clear
8-04	2318	D*	21.0	20.0	E	0-5	calm		-
8-07	1515	D*	21.5	21.0	N	5-10	NW	.3	sunny & haze
8-19	1600	D*	23.0	-	calm		calm		sunny & haze
8-20	2131	D*	22.0	17.0	SE	0-5	calm		clear
8-20	1303	D	23.4	20.0	calm		calm		sunny & haze
8-19	2330	D	21.8	16.4	SE	5-10	calm		clear
8-20	1521	E	24.0	15.2	calm		calm		sunny & haze
8-19	1714	G	22.2	17.9	SW	0-5	SW	0-.2	sunny & haze
8-19	2158	G	21.5	18.1	NE	5-10	NE	0-.2	clear
8-19	1558	H	21.4	14.5	calm		calm		sunny & haze
8-19	2044	H	22.4	12.7	calm		calm		pt. cloudy
8-04	2356	N*	20.3	20.0	E	0-5	calm		-
8-07	1545	N*	21.5	21.5	N	5-10	NW	.3	sunny & haze
8-19	1632	N*	24.0	24.0	calm		calm		sunny & haze
8-20	2203	N*	22.0	21.0	SE	0-5	calm		clear
8-05	0012	P*	20.4	20.3	E	0-5	calm		-
8-07	1605	P*	21.5	21.5	N	5-10	NW	.3	sunny & haze
8-19	1643	P	24.0	24.0	calm		calm		sunny & haze
8-20	2217	P*	21.5	21.0	SE	0-5	calm		clear
9-09	1630	A	22.0	21.5	NE	0-5	calm		sunny & haze
9-09	1640	A*	22.0	21.5	NE	0-5	calm		sunny & haze
9-08	2324	A	19.1	19.2	SE	0-5	calm		pt. cloudy
9-08	2334	A*	19.1	19.2	SE	0-5	calm		pt. cloudy
9-24	2145	A*	15.7	15.7	S	10-15	W	.7	pt. cloudy
9-25	1420	A*	17.0	17.0	NW	10-15	NW	.9	clear
9-09	1614	B	20.9	20.6	NE	0-5	calm		sunny & haze
9-09	1605	B*	20.9	20.6	NE	0-5	calm		sunny & haze
9-09	2143	B	18.0	18.0	E	0-5	calm		pt. cloudy
9-09	2153	B*	18.0	18.0	E	0-5	calm		pt. cloudy
9-24	2212	B*	15.3	15.3	S	10-15	W	.7	pt. cloudy
9-25	1300	B*	16.7	16.7	NW	10-15	NW	.9	clear
9-09	1520	F	21.3	21.1	NE	0-5	calm		sunny & haze

Table C1A. Continued.

Starting date	Starting time	Station	Temp C Surface	Temp C Bottom	Wind Dir. from	Wind Speed mph	Waves Dir. from	Waves Height (m)	Weather
9-09	1525	F*	21.3	21.1	NE	0-5	calm		sunny & haze
9-09	2247	F	18.0	18.0	E	0-5	calm		pt. cloudy
9-09	2238	F*	18.0	18.0	E	0-5	calm		pt. cloudy
9-24	2255	F*	15.7	15.7	S	10-15	W	.7	pt. cloudy
9-25	1420	F*	17.0	17.0	NW	10-15	NW	.9	clear
9-09	1703	C*	19.2	18.3	NE	0-5	calm		overcast & haze
9-11	2255	C*	19.5	19.5	SE	0-5	W	.2-.3	-
9-10	1307	C	19.7	19.0	calm		calm		clear
9-09	2258	C	19.0	17.5	SE	5-10	calm		pt. cloudy
9-09	1650	D*	20.0	18.6	NE	0-5	calm		overcast & haze
9-11	2217	D*	19.5	19.4	SE	0-5	W	.2-.3	-
9-10	1218	D	19.5	18.0	calm		calm		clear
9-09	2244	D	19.2	17.2	SE	5-10	SW	<.2	pt. cloudy
9-10	1503	E	19.5	10.0	calm		calm		clear
9-09	1707	G	19.2	17.6	calm		calm		pt. cloudy
9-09	211o	G	19.5	17.5	SW	5-10	calm		pt. cloudy
9-09	1552	H	19.5	17.5	calm		calm		clear
9-09	2000	H	19.0	16.8	calm		calm		pt. cloudy
9-09	1718	N*	19.4	17.8	NE	0-5	calm		overcast & haze
9-11	2312	N*	20.0	20.0	SE	0-5	W	.2-.3	-
9-09	1732	P*	20.6	19.1	NE	0-5	calm		overcast & haze
9-11	2329	P*	20.0	20.0	SE	0-5	W	.2-.3	-
10-08	2207	A	13.3	13.3	S	5-10	SW	.5-.6	rain
10-09	1500	A	14.5	14.7	W	0-5	W	.5-.6	clear
10-08	2015	B	12.8	12.8	S	5-10	SW	.5-.6	overcast
10-09	1404	B	14.8	14.6	SW	5-10	W	.6	clear
10-08	2210	F	12.8	13.7	S	5-10	SW	.5-.6	overcast
10-09	1310	F	14.0	14.0	SW	5-10	SW	.9	sunny & haze
10-08	1500	C	13.5	13.0	SW	10-15	SW	.6-.9	pt. cloudy
10-08	2031	C	14.0	13.5	S	10-15	SW	.3-.6	pt. cloudy
10-08	1347	D	14.0	13.5	SW	10-15	SW	.6-.9	pt. cloudy
10-08	1914	D	14.0	13.5	S	5-10	SW	.6	pt. cloudy
10-08	1200	G	13.5	13.0	SW	10-15	SW	.6-.9	pt. cloudy
10-07	2101	G	13.0	13.0	SE	5-10	NW	.9-1.2	clear
10-08	1045	H	13.0	13.0	SW	5-10	SW	.6-.9	pt. cloudy
10-07	1946	H	13.0	13.5	NE	0-5	NW	.9-1.2	pt. cloudy
11-26	1555	A	5.5	6.0	SE	10-15	calm		overcast
11-26	1950	A	4.7	4.6	SE	10-15	calm		pt. cloudy
11-26	1625	B	5.2	4.2	S	5-10	calm		-
11-26	2020	B	5.0	5.0	SE	10-15	calm		pt. cloudy
11-26	1700	F	5.0	5.1	SE	10-15	calm		pt. cloudy
11-26	1750	F	5.0	5.1	SE	10-15	calm		pt. cloudy
11-10	2347	C	10.1	9.9	SE	10-15	S	.2	rain
11-10	2225	D	10.5	10.1	SE	0-5	S	.2	rain
11-10	2037	G	9.9	10.1	SE	5-10	calm		rain
11-10	1918	H	10.5	10.5	SE	5-10	calm		rain

*Indicates a sled tow.

calculations. Volume of water filtered at beach stations in 1973 ranged from 1.7-6.6 m^3; for deepwater stations water filtered ranged from 0.8-32.4 m^3. Reasons for this variation were related to algae blooms and suspended particles from storm activity which clogged nets rapidly, and differences in currents and wave height and direction which affect boat movement and thus flowmeter readings. Numbers of larvae captured were adjusted to number per 1000 m^3 by calculation to agree with published reports (Wells 1973) and to avoid reporting less than whole numbers. Occasionally the flowmeter was unavailable for some beach station tows in 1973. In these cases, an average value of 3.96 m^3 [all beach readings, 233 $\pm$ 10 (SE) revolutions, N (number of values) = 28] was used. In one instance during deepwater tows, an average value [14.0 m^3 - 826 $\pm$ 36.8 (SE) revolutions, N = 63] was used because a leaf had been caught in the meter. During April and May, the 1000's indicator was missing from the flowmeter. Flowmeter readings for June and July were averaged, and two standard deviations on either side of the mean were calculated to be 242 and 1410 [$\bar{x}$(mean) = 826]. From these data we concluded that all readings less than 242 in April and May 1973 should have had a 1000 added to them, which was done for nine flowmeter readings.

Because the net when brought up from lower levels passed through the water column above, total numbers captured in all tows below the surface in 1973-1974 were adjusted by calculation to compensate for this upper strata contamination. Through swimming pool tests, towing the net vertically in 2.6 m of water, we determined that the net filtered 0.476 m^3 [28 $\pm$ 0.52 (SE) revolutions] of water or 0.18 m^3 for each meter of water through which the net passed. Numbers of fish larvae that would have been captured passing through upper waters (assuming 0.18 m^3 was filtered for each meter) were calculated assuming average distribution of larvae in any given tow. Then total numbers of fish larvae caught at 1 m, 2 m and the steptow were adjusted by subtraction to account for larvae caught while passing through upper layers, then multiplied by a factor to get the catch in terms of numbers per 1000 m^3. In 1974 the steptow was dropped and only discrete tows were made. A similar correction was used to eliminate larvae caught as the net was retrieved through the water column above the tow. The only change was that such corrections were made by computer for each length interval, not just using total numbers, regardless of length, as was done in 1973. This was done so as not to remove by calculation a certain length group of fish which actually belonged in the sample. For example in the case where only large larvae were distributing themselves on the bottom at night and newly hatched, smaller larvae were found exclusively at the surface, only the smaller larvae will be removed from the sample collected near the bottom.

Supplementary tows were also performed using a benthic fish larvae sled (Fig. C1) in an attempt to sample demersal larvae (e.g., spottail shiners) and document whether pelagic larvae were concentrating on or near the bottom during certain times of the day or night. A no. 2 plankton net, as was used for our regular larval tows, was fitted to a rectangular, stainless steel frame (20 x 57.5 cm). The net and frame were mounted inside a 194-cm long aluminum sled designed for this apparatus. The sled was pulled using the D.

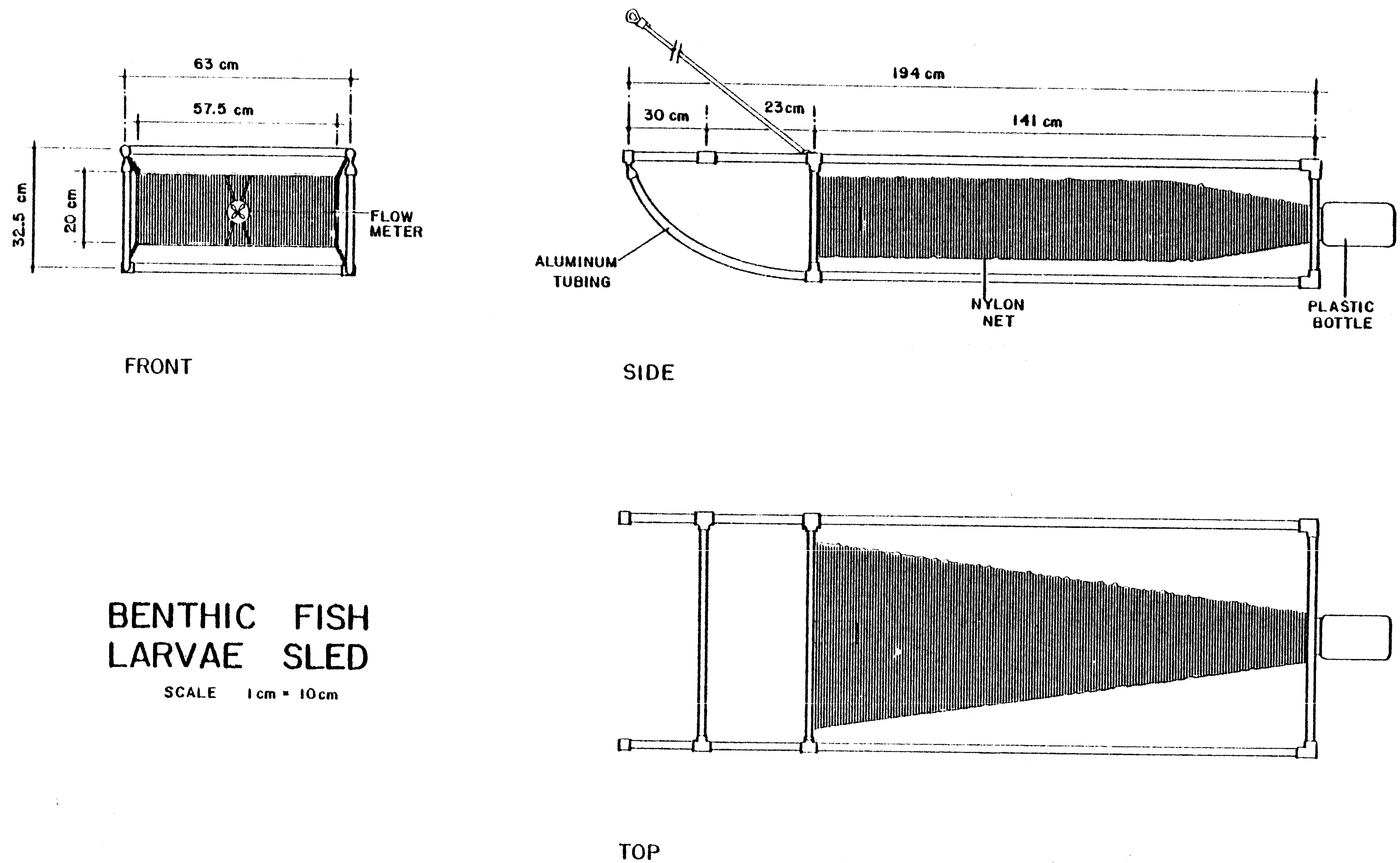

FIG. C1. Benthic fish larvae sled used to collect demersal larval fish. A no. 2 nylon 0.5-m diameter plankton net and Rigosha flowmeter were mounted on the aluminum frame as shown. A pint mason jar, fastened to the net by screwing into a permanently mounted wide mouth jar ring for ease of removal, was inserted into the plastic bottle to prevent damage to the jar.

C. Cook, a 10-m inboard cruiser, at about 8 km/h or a 5-m outboard Boston Whaler at about 4 km/h. With a Rigosha flowmeter rigidly fixed in the center of the net mouth, the entire apparatus was calibrated in a pool; one revolution of the flowmeter equalled 10.9 liters. The sled was towed for 5 min on the bottom on a variable sampling schedule during 1974 at seven stations, including the three beach stations (A, B, F) and four stations off the Cook plant at 1.5 m - station P, 3 m - N, 6 m - C and 9 m - D (see Fig. B1). Tows were first performed in 1974 during day and night at least once per month and more often when possible at beach stations. Beach station tows were done by two people pulling the sled a distance of 60 m using two separate ropes so the sled passed over bottom not walked on by the people sampling.

Fish larvae samples were sorted with the use of binocular microscopes and a lighted, sorting chamber (Dorr 1974a). All larvae were removed, identified, total length measured to the nearest 0.1 mm and data recorded on a computer coding form for keypunching. Larvae were identified using taxonomic keys (Fish 1932, Lippson and Moran 1974, Norden 1967, Nelson and Cole 1975), voucher specimens when available, knowledge of spawning times from our field sampling and a summary of key characters (to be discussed later in this section) gleaned from the literature, rearing specimens and our own experience working with the larvae.

A computer program was written to plot length-frequency histograms for larval fish which used total length intervals of 0.5 mm, i.e., 1.6-2.0 mm, etc. Since duplicate tows were made for beach stations A, B and F, mean number of larvae in each length interval was plotted.

To compare differences in lengths of larvae between habitats, day and night and different gear types the entire sample of larvae from a particular category were pooled and the length-frequency histogram (expressed as percent of total) plotted. The number of larvae involved in the calculation (N) was given as well as the mean ($\overline{x}$) and standard error (SE).

Fish Eggs

Up to 100 fish eggs were removed from a sample and those remaining in the sample were counted using a hand counter or in cases where large numbers were present, the sample was split with a Folsom plankton splitter and a subsample enumerated. Data on fish eggs are presented as numbers per 1000 m^3 using the same flowmeter methodology discussed for fish larvae. Gross identification for discussion purposes was based on size, shape and seasonal occurrence of fish eggs.

RESULTS AND DISCUSSION

Most Abundant Species

Alewife --

Introduction -- From about April-May through September and sometimes

October either the adult and juvenile or larval alewives numerically dominate the inshore fish populations of southeastern Lake Michigan. No other fish species invades the inshore region in such large numbers, spawns over 3 mo or has its larvae present in the inshore epilimnetic waters for as long a time period or in such large concentrations as this recent marine immigrant to Lake Michigan. Alewives, because of their tremendous numbers and planktivorous food habits, have been suspected either directly or indirectly, of affecting many of the native fish stocks in Lake Michigan; e.g., yellow perch and lake herring (Smith 1968b, Wells and McLain 1973). Because of their abundance in the vicinity of the Cook Plant, alewife larvae are entrained and adults impinged more than any other species, as might be expected. It was thus important to document the distribution of alewife larvae in the area, for at least three reasons. First, determining the distribution of alewife larvae in the vicinity of the plant will establish where maximum concentrations of larvae were found so that if any mitigative action is planned, effort can be directed in the most efficient or appropriate direction. In addition, future water intake siting could benefit from knowledge about the distribution of this ubiquitous fish larvae in southeastern Lake Michigan. Second, this knowledge will help to develop a grasp of how many larvae are present around the plant, so as to better put entrainment losses in perspective. Lastly, the Great Lakes states, with Michigan taking the lead, have initiated a salmonid restocking program after the catastrophic decline of the lake trout. Alewives, the principal food of these salmonids, are critical to survival and continuity of the program. More information is required to understand the early life history of the alewife, since reproductive failure by alewives or demise of alewife larvae would have a grave effect on Pacific salmon, since none of the remaining forage species in the lake (smelt, sculpins, spottails) with the possible exception of the coregonids, are either suitable food for salmonids (our data show few are eaten) or could with any likelihood withstand the amount of predation now sustained by the alewife population.

Seasonal occurrence -- Alewife larvae were first collected in 1973 during the 18-20 June field trip, when they were abundant in beach and open water station fish larvae tows (Figs. C2 and C3). None were collected on the 14-18 May 1973 field trip a month earlier. In 1974, with more intensive sampling, alewife were first recorded on 1 June in low numbers at beach station F (Dunes) (a 4.9-mm larva - surface net tow - Fig. C4) and at 9-m station D (a 5.5-mm larva - bottom sled tow - Table C1), indicating initiation of some spawning during late May 1974. On 4 June 1974, again at beach station F, a 3.5-mm alewife larva was captured in a surface net tow.

By the major field trip of 11-12 June 1974, alewives were abundant at all beach and 6- and 9-m open water stations. They remained abundant at all stations, with some even found in epilimnetic waters at 21 m (station E) during June, July and the first part of August. Numbers of larvae collected in nets declined drastically in September and only 10 larvae (16-24 mm) were taken in all field collections in October. None were collected at any stations in November although one 23-mm specimen was entrained on 20 November 1974. Spawning in 1974 by alewives was thus verified from sometime

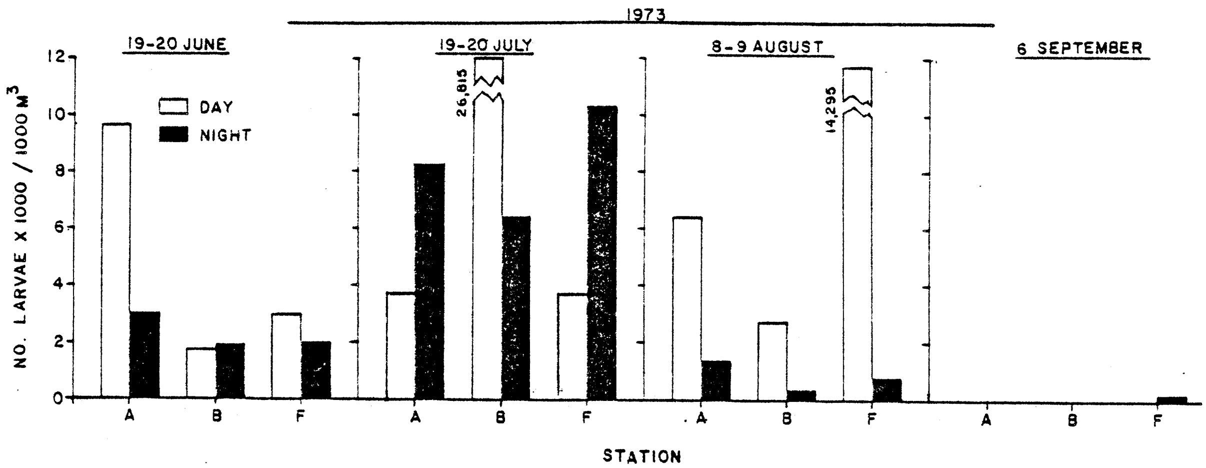

FIG. C2. Distribution of alewife larvae in no./1000 m^3 during day and night sampling, June-August 1973 at Cook Plant beach stations. Each bar represents the mean of two observations.

in late May through all August. Evidence for this was first occurrence of alewife larvae on 1 June and many recently hatched larvae collected during the whole of August and on 9-10 September 1974. September alewife larvae were collected at 9-m stations D and H and were 5.2 and 5.0 mm respectively. Total length for newly hatched alewife larvae was given as 4.3-5.1 mm by Norden (1967) and 3-5.5 mm by Mansuetti and Hardy (1967). From our field collections we have measured larvae as small as 3 mm which were fully intact. Edsall (1970) found that alewife hatched in about 2 days at 30 C, 5 days at 20 C and 7 days at 15 C. Our data thus establish peak spawning for alewives from about mid-June through all July. Reproductive activity tapers off on either side of those dates, but continues into late summer, early fall.

Wells (1973) in his 1972 fish larvae surveys over the east and west shores of Lake Michigan found a few alewives in net tows on 27-28 May off Saugatuck, which is 78-km north of Cook. In 1973 studies, Wells (1974) found one alewife in net collections on 24 May again off Saugatuck. Wells thought that alewife larvae became abundant on the east shore earlier in 1973 than in 1972. He also concluded that the entire nearshore area along the east side of Lake Michigan at least as far north as Frankfort was used heavily as a nursery ground by alewives.

Alewives have been reported to spawn in rivers (the Kalamazoo River near Saugatuck, about 3-4 km upstream from the river mouth in Lake Michigan--Edsall 1964), in the shallow, inshore water of Lake Michigan near the Zion Plant during early summer (Otto et al. 1976) and they moved into the inshore waters of Milwaukee Harbor at the end of April and early May (Norden 1967). For more details on adults see SECTION B - Alewife. We have observed spawning by adult alewives several times, always at night at beach stations (1 m) and open water stations (6 and 9 m) during our seining,

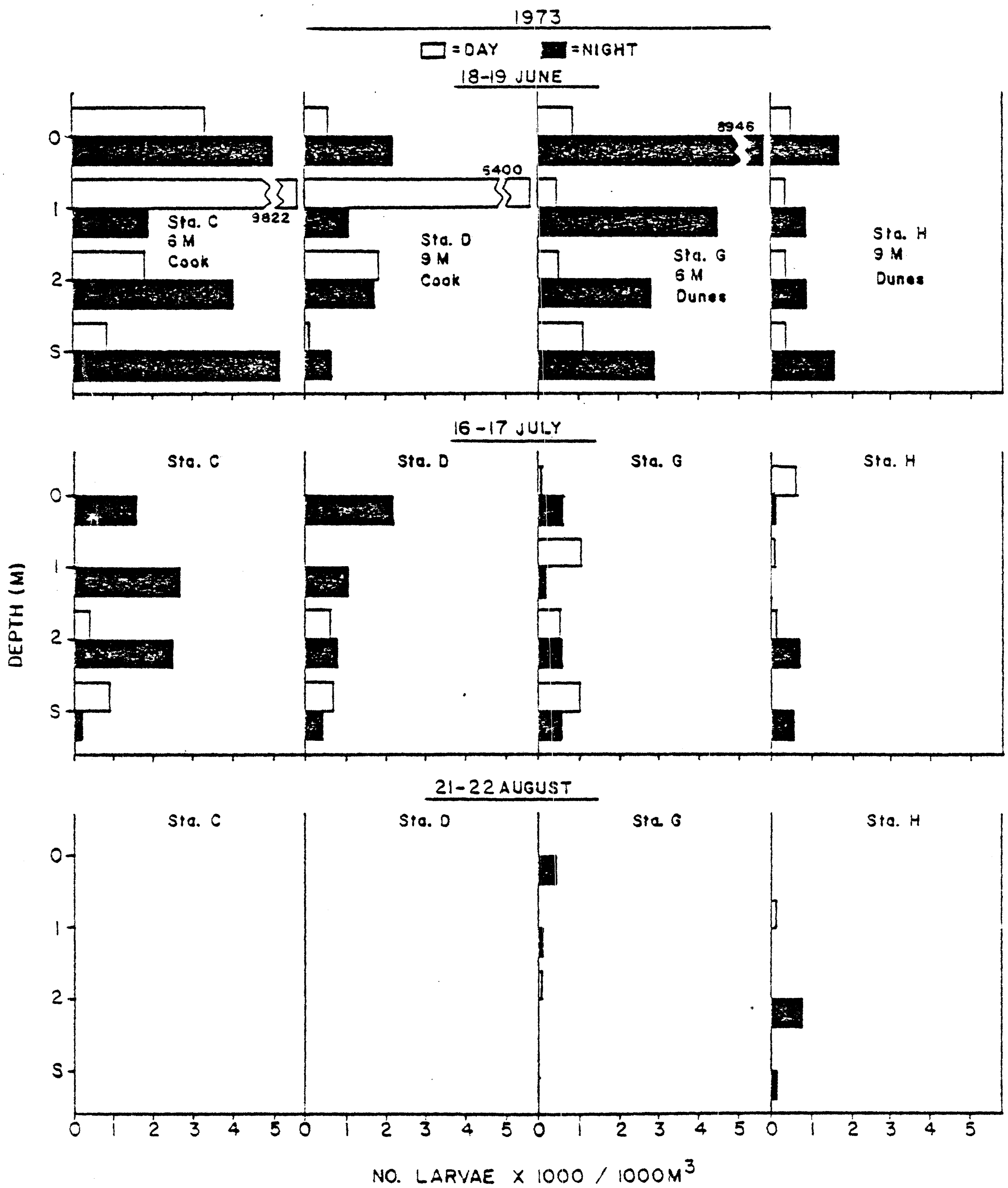

FIG. C3. Vertical distribution in no./1000 m^3 of alewife larvae captured during day and night sampling in 1973 at Cook Plant and Warren Dunes openwater stations, southeastern Lake Michigan. S = steptow - see METHODS for an explanation.

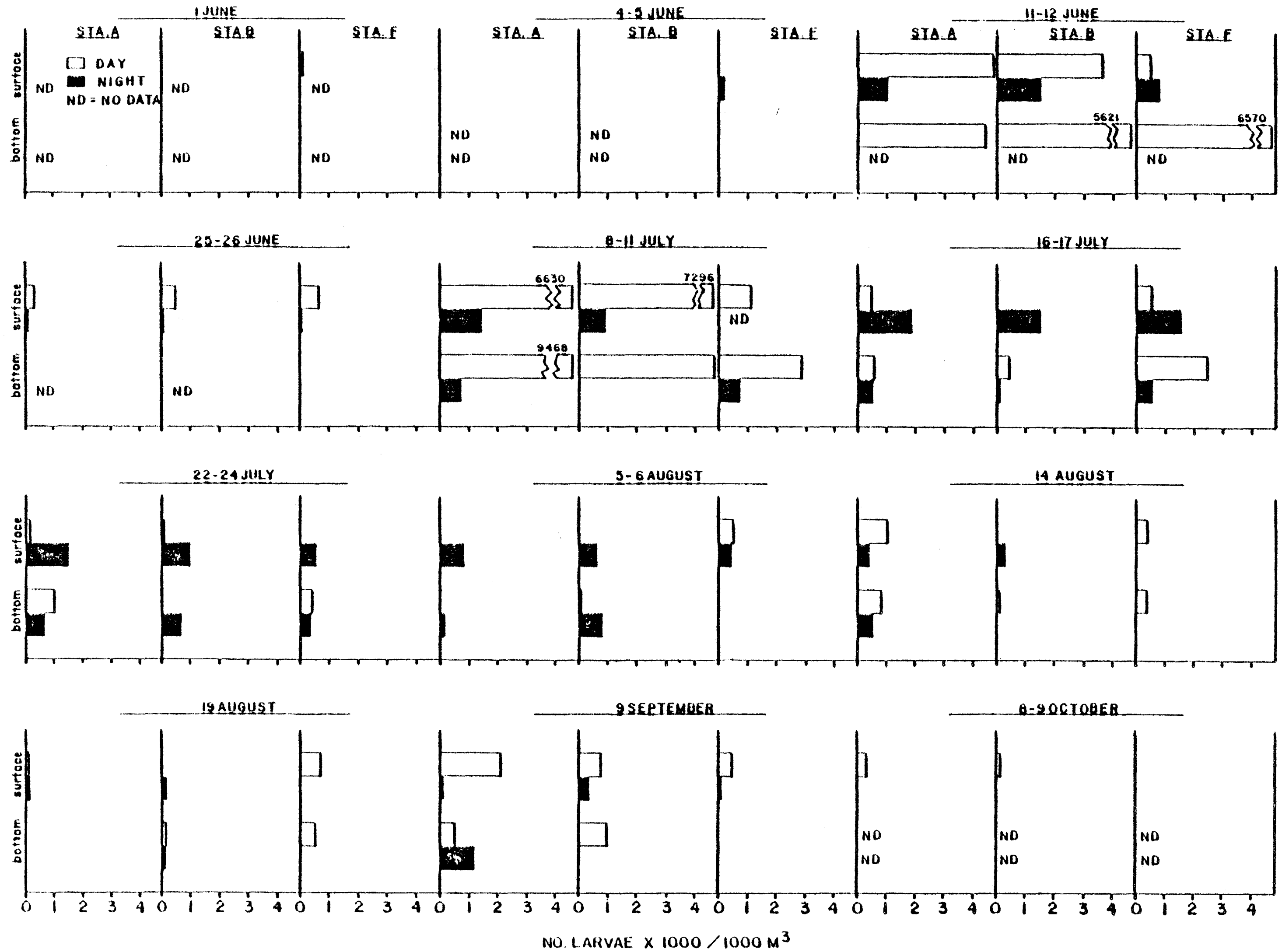

FIG. C4. Vertical distribution of alewife larvae during day and night sampling, June-October 1974 at Cook Plant beach stations. Surface samples were collected in duplicate and the mean shown; only one tow was made with the benthic sled for bottom data. ND = no data.

TABLE C1. The number of larvae (no/1000 m^3) captured in sled tows during 1974 at beach (A, B, F), transition (P, N) and openwater stations (C, D) in the vicinity of the Cook Plant, southeastern Lake Michigan. Al = alewife, SM = rainbow smelt, SP = spottail shiner, SS = slimy sculpin, JD = johnny darter, TP = trout-perch, ZZ = no larvae captured.

Date	Diel Period	Temp (C)	Station A 1 m N. Cook	Station B 1 m S. Cook	Station F 1 m W. Dunes	Station P 1.5 m Cook	Station N 3 m Cook	Station C 6 m Cook	Station D 9 m Cook
17 Apr	Day	8.0				ZZ	ZZ	ZZ	ZZ
8 May	Day	9.2				SM 298	ZZ	SM 45	ZZ
13 May	Day	9.0-10.0				SP 161	SP 46	ZZ	SM 1202
1 Jun	Day	18.0	ZZ	ZZ	ZZ	SP 214	ZZ	ZZ	AL 64
11 Jun	Day	14.2-18.6	AL 4275 YP 1498 SP 426	AL 5621	AL 6570 SP 328	AL 12,776 SP 4256	AL 643 SP 214	AL 138	AL 2421
12 Jun	Night	14.5-16.7				AL 964 SP 1285	AL 365 SP 147	AL 544 SP 25	AL 686 SS 49
20 Jun	Day	15.7-19.2				AL 245	ZZ	AL 75	AL 52
25 Jun	Night	15.1			ZZ				
26 Jun	Day Night	15.0-17.3 12.5-13.0	ZZ	ZZ	SP 164	SP 42 AL 86 SP 344 SM 258	SP 65 SS 46	AL 893 AL 369 SM 61	AL 957
8 Jul	Day	22.5	AL 9468 XX 338	AL 5410 SP 1014	AL 2704 SP 338				
9 Jul	Day	19.8				AL 5362 SP 229	AL 736 SP 156	AL 209	ZZ

TABLE C1. Continued.

Date	Diel Period	Temp (C)	Station A 1 m N. Cook	Station B 1 m S. Cook	Station F 1 m W. Dunes	Station P 1.5 m Cook	Station N 3 m Cook	Station C 6 m Cook	Station D 9 m Cook
10 Jul	Night	17.6			AL 676 SP 29,423	SP 180	AL 57 SM 57	ZZ	JD 123 SS 61
11 Jul	Night	16.9	AL 760 SM 380 SP 12,542	SP 4732	AL 540 SP 15,420				
16 Jul	Day	15.8				AL 1300 SP 5525	AL 564	AL 176	AL 666
	Night	16.3	AL 481	AL 184 SP 2030		SP 6944	SP 65	ZZ	ZZ
17 Jul	Day	22.0	AL 573	AL 364 SP 1274	AL 2363				
22 Jul	Night	16.0	AL 592 SP 4150	AL 505 SP 5220	AL 388 SP 2527				
24 Jul	Day	14.6	AL 1014 SP 4132	SP 192	AL 419	AL 431	ZZ	AL 1050	AL 486
	Night	14.8				AL 161 SP 2096	ZZ	AL 273	AL 643
4 Aug	Night	20.0					AL 117 SP 473		AL 275
5 Aug	Night	19.8	AL 161 SP 1129	AL 880 SP 1760	SP 456	AL 57 SP 1655		AL 315	
6 Aug	Day	22.4	SP 852	AL 153 SP 153	SP 546				

TABLE C1. Continued.

Date	Diel Period	Temp (C)	Station A 1 m N. Cook	Station B 1 m S. Cook	Station F 1 m W. Dunes	Station P 1.5 m Cook	Station N 3 m Cook	Station C 6 m Cook	Station D 9 m Cook
7 Aug	Day	21.0-24.0				AL 588	AL 379	AL 31	AL 44
						SP 124			
14 Aug	Day	18.7	AL 703	AL 169	AL 302				
			SP 141	SP 169	SP 151				
	Night	15.8	AL 338						
			SP 845	SP 7776	SP 3603				
19 Aug	Day	23.6	SP 1232	AL 152	AL 481	SP 2338	AL 601	ZZ	AL 31
				SP 12,354					
	Night	19.9-21.7	SP 4258	AL 133	SP 5200	AL 64	AL 249	ZZ	AL 91
				SP 10,554		SP 160			TP 46
9 Sep	Day	19.4	AL 460	AL 1015	ZZ	AL 281	AL 57	ZZ	ZZ
				SP 203					
	Night	18.4	AL 1260	SP 836	SP 5255				
11 Sep	Night	19.7				SP 42	ZZ	AL 86	AL 43
24 Sep	Night	15.6	ZZ	ZZ	ZZ				
25 Sep	Day	17.0	ZZ	ZZ	ZZ				

gillnetting, SCUBA diving and trawling. Usually, one large alewife, presumed to be a female, will swim rapidly to the surface and be immediately followed by four to six smaller individuals, believed to be males. They often break the surface at this point and all come together at which time we suspect eggs and sperm are released. Once we were able to net and snag a few of the individuals participating in this activity and all were ripe-running fish, most captured were males, but we did catch one or two females. After this "spawning event" the entire group of fish disappears as they swim to lower depths. The entire sequence takes less than 3-4 s. We usually observed these fish on calm nights and could hear water breaking everywhere. They were observed with boat lights, flashlights and without lights on moonlit nights. Since tremendous numbers of newly-hatched larvae and eggs were collected in our nets during June and July when these "spawning acts" were observed and large numbers of alewife eggs were noted on the bottom by SCUBA divers, in sled tows and in yellow perch stomachs, we have no doubt that spawning occurred in the inshore (0-9 m) waters of southeastern Lake Michigan. There are no large rivers close enough to supply newly-hatched larvae in the quantity we observed around the Cook Plant and the two small streams in the area are almost dry during peak spawning by alewives.

Larvae collected at the Cook Plant would not necessarily have been spawned there, depending on prevailing wind and currents at the time of sampling. Our data (both field and entrainment) indicate that newly-hatched larvae are essentially planktonic and at the mercy of currents. Other studies have documented the importance of prevailing winds in influencing where newly-hatched larvae were transported. Coles et al. (1977) found that perch larvae (Perca fluviatilis) were spawned in the southwest end of Llyn Tegid, North Wales, but were carried to the northwest end by prevailing winds, a phenomenon also noted for yellow perch (Noble 1970) and walleye (Houde and Forney 1970) in Oneida Lake. Houde (1969) felt from his laboratory studies that yellow perch in Oneida Lake would be transported passively by currents greater than 4-10 cm/s until larvae exceeded 9.5 mm TL. Walford (1938) found haddock larvae in Georges Bank were dispersed from the bank by currents and, depending on wind direction, could result in transport to the deep ocean where most would perish. Sette (1943) found a similar relationship for mackerel larvae and in addition stated that larvae less than 8-10 mm were in a passive phase (planktonic) and were transported by prevailing currents. After this size, mackerel grew fins and were able to resist currents and control their distribution (active phase).

Diel distribution -- Alewife larvae were generally caught in larger quantities at night than during the day, especially during July and August when alewives over a wider length range were present. This phenomenon, due entirely to net avoidance by larger larvae during the day, was best exemplified by the open water 1973-1974 net tow data (Figs. C3 and C5). Of the 38 pairs of tows (where alewife were present) done during day and night in June, July and August at the four open water stations in 1973 (Fig. C3), day catches were larger than the comparable night catches only eleven times. In the other 27 cases when night catches were greater, they were

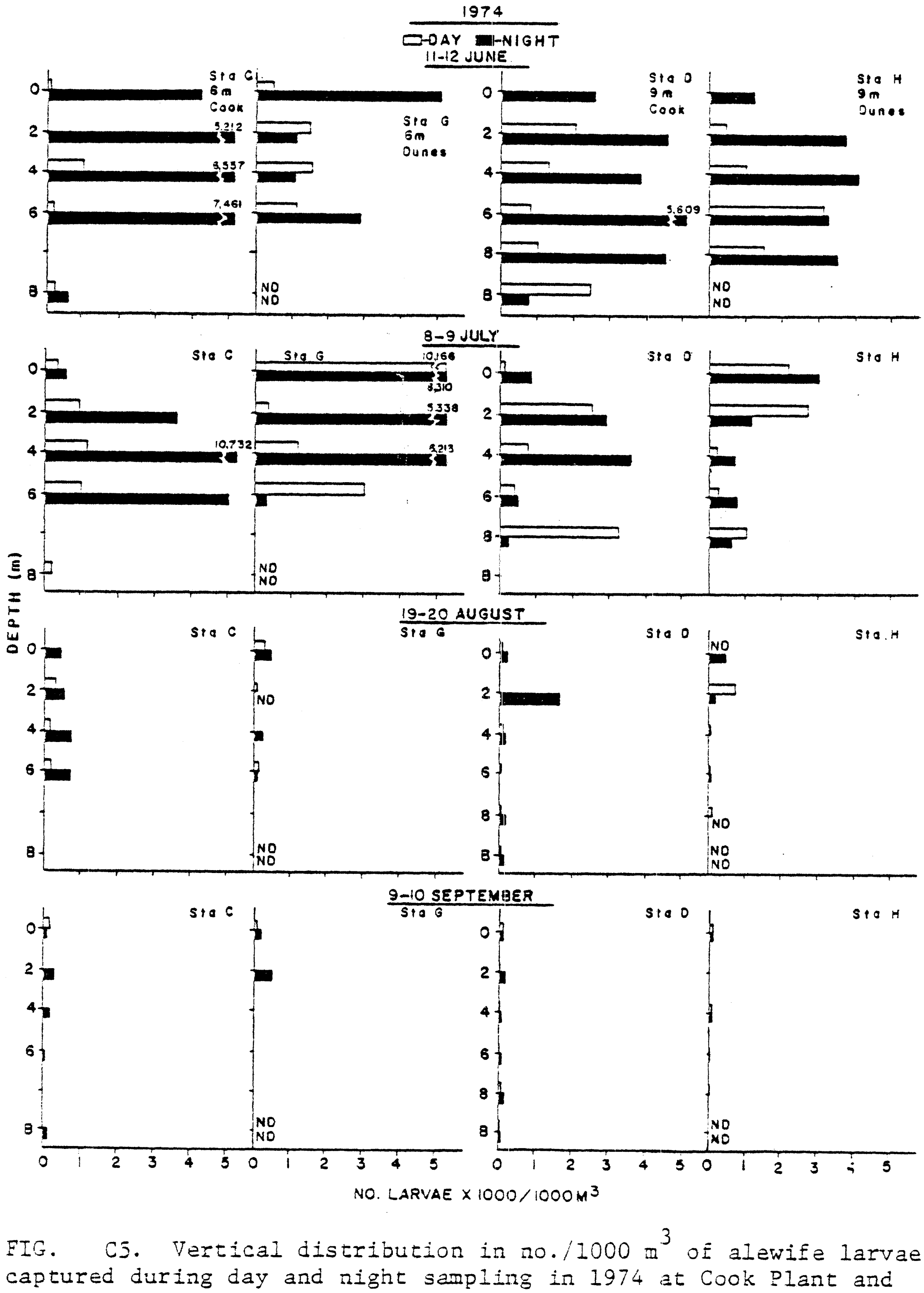

FIG. C5. Vertical distribution in no./1000 m^3 of alewife larvae captured during day and night sampling in 1974 at Cook Plant and Warren Dunes openwater stations, southeastern Lake Michigan. B = sled tow data, present only for stations C and D. ND = no data.

sometimes 2-8 times larger than the corresponding day catch, particularly during June. The same patterns were clearly evident in July and August, though fewer larvae were captured. In 1974 open water tows during June-September (Fig. C5) which included sled tows at stations C and D (6 m and 9 m - Cook), 70 pairs of tows contained larvae. Of these, 53 night tows had catches of alewife larvae which were larger than the comparable day tow. Net avoidance is thus very important when considering open water station data, and attempts to estimate populations of alewife larvae should be based on data collected during the nighttime.

Data collected at beach stations in 1973-1974 (Figs. C2 and C4) did not wholly follow the pattern of more larvae caught at night. For example, six of the 10 pairs of tows collected June-September 1973 at beach stations had higher catches during the day than the night. In June-October 1974, 46 pairs of beach tows contained larvae and 65% of these tows had day catches which were larger than comparable night catches. Examination of length-frequency histograms for 1973 and 1974 net and sled tow data (Figs. C6, C7 and C8) showed a general trend of larger alewife larvae caught during the day at beach stations than those caught at night at the same station. This pattern was not always consistent and was somewhat masked by pooling data from all similar stations. Individual 1973 beach station data for alewives collected during June-August (Jude et al. 1975, pp. 238-240) showed clearly that some type of offshore movement by larger larvae was occurring during the night. Evidence for this conclusion is based on three findings. First, the length-frequency distributions for alewives at beach stations during 1973-1974 (Figs. C6 and C7) showed in all but two cases (July and August 1974) that more larvae were collected during the day than at night, and that mean length of day-caught larvae was larger than the mean length of night-caught larvae at the same stations. This effect was probably greatly magnified when the net avoidance capabilities of alewives exhibited at open water stations are taken into consideration. Undoubtedly, the larvae we caught during the day at beach stations underrepresented actual densities that were probably present during the time of sampling. Little net avoidance by alewives is expected during the night, yet almost half as many larvae were collected during the night as during the day. Secondly, the graphs in Jude et al. (1975) showed that smaller alewives (4-6 mm - newly hatched) were collected in about the same numbers during day and night with a slight tendency for more smaller larvae to be collected at night (also observed for 1974 beach station data). Significantly longer larvae (>6 mm) were generally collected in larger numbers during the day than at night. Lastly, other data we have collected south of Grand Haven (Jude et al. 1978) show this same pattern for alewives at beach stations.

It is our opinion that this nighttime offshore movement and daytime onshore movement to the beach zone may be related to water temperature. Alewives are usually found in the warmest water available and during spring and early summer the shallow beach zone waters are the warmest available during the day and may cool down at night causing offshore movements. This offshore, nocturnal movement might also be related to feeding.

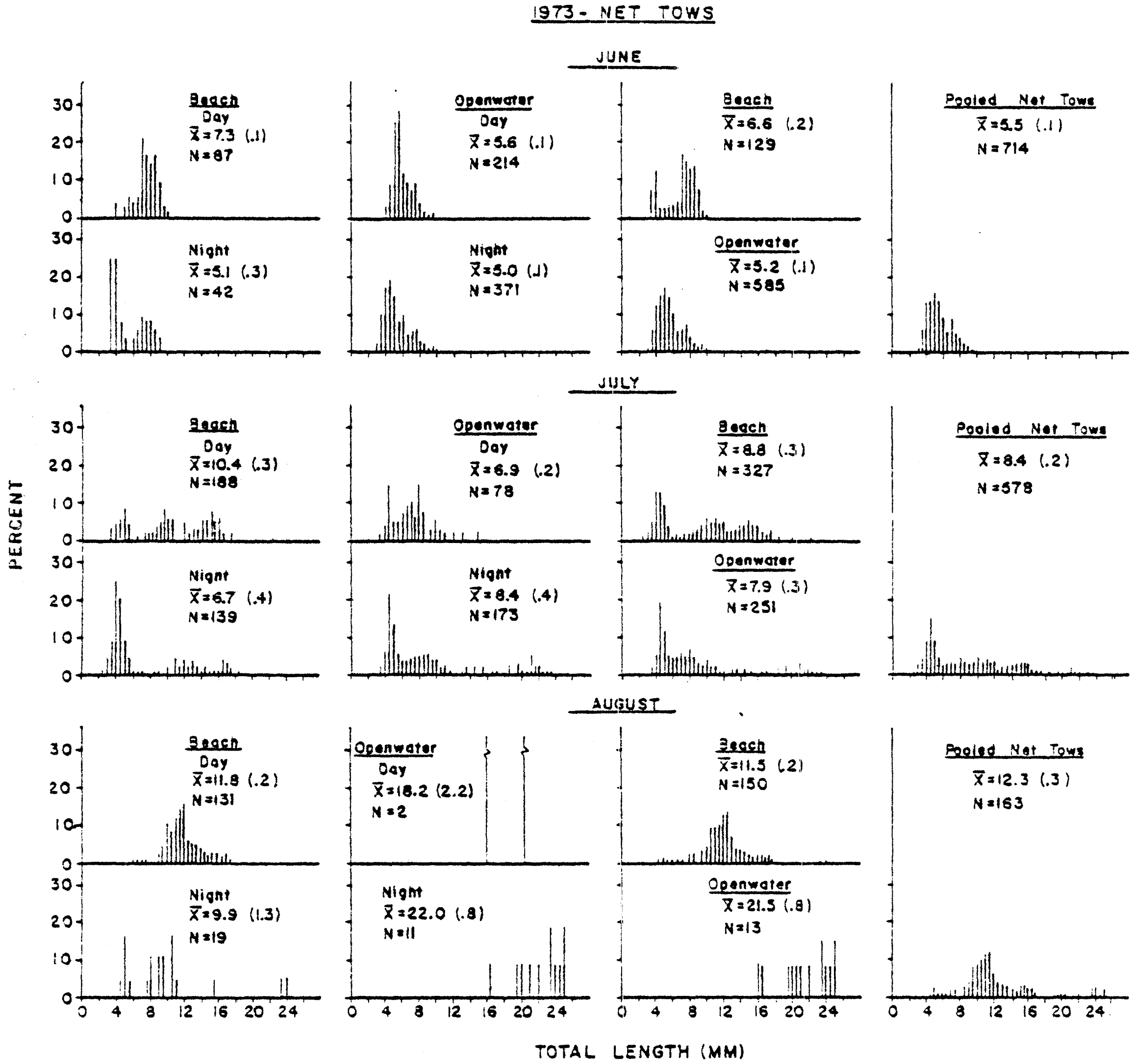

FIG. C6. Monthly length-frequency histograms for alewife larvae caught in net tows during June-August 1973 from Cook Plant study areas, southeastern Lake Michigan. Data were selectively pooled over day and night, station and depth as indicated. N = number of larvae used in the comparison, $\overline{X}$ = mean length of larvae. Standard error is given in parenthesis.

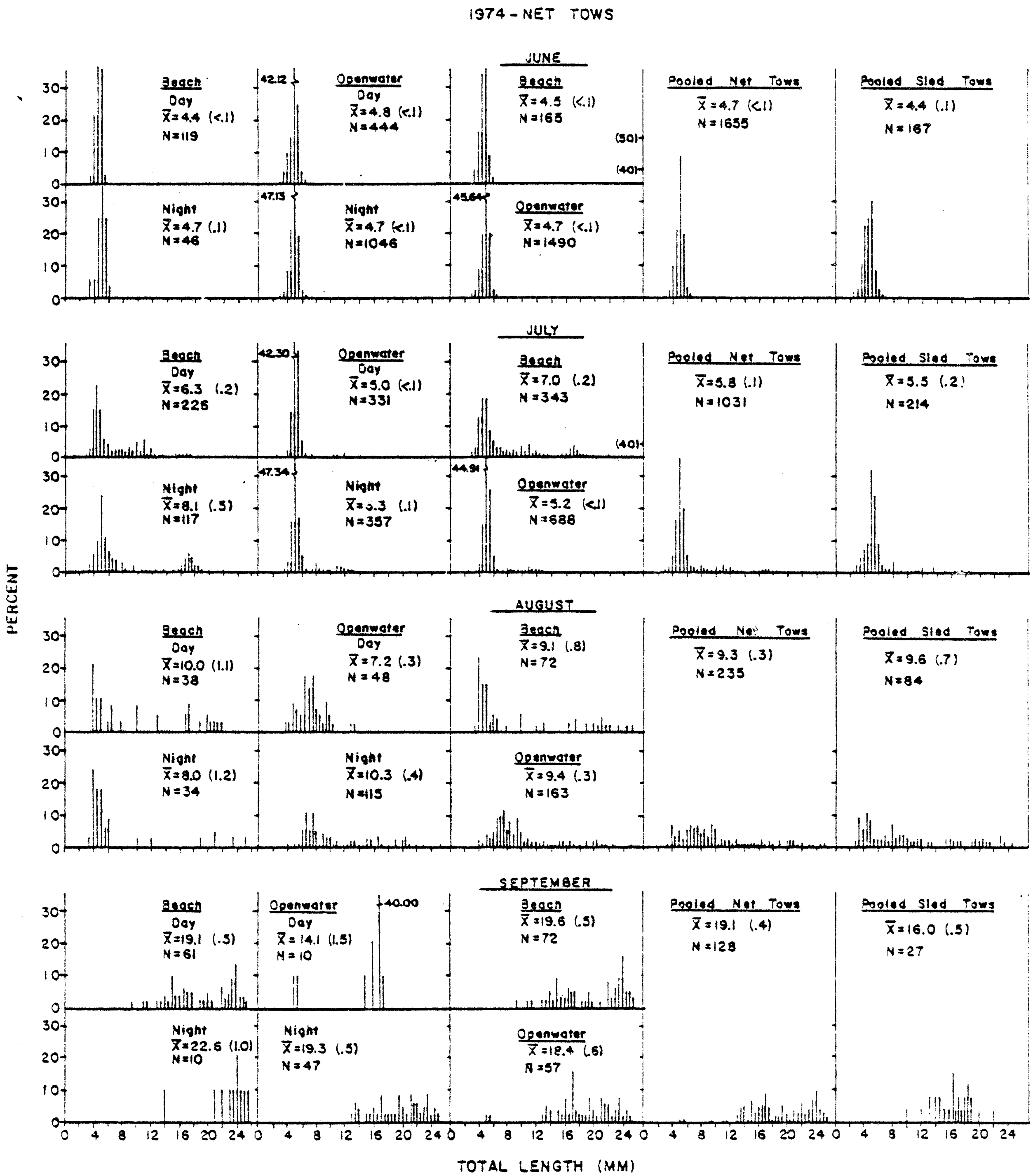

FIG. C7. Monthly length-frequency histograms for alewife larvae caught in net tows during June-September 1974 from Cook Plant study areas, southeastern Lake Michigan. Data were selectively pooled over day and night, station and depth as indicated. N = number of larvae used in the comparison, $\overline{X}$ = mean length of larvae. Standard error is given in parenthesis.

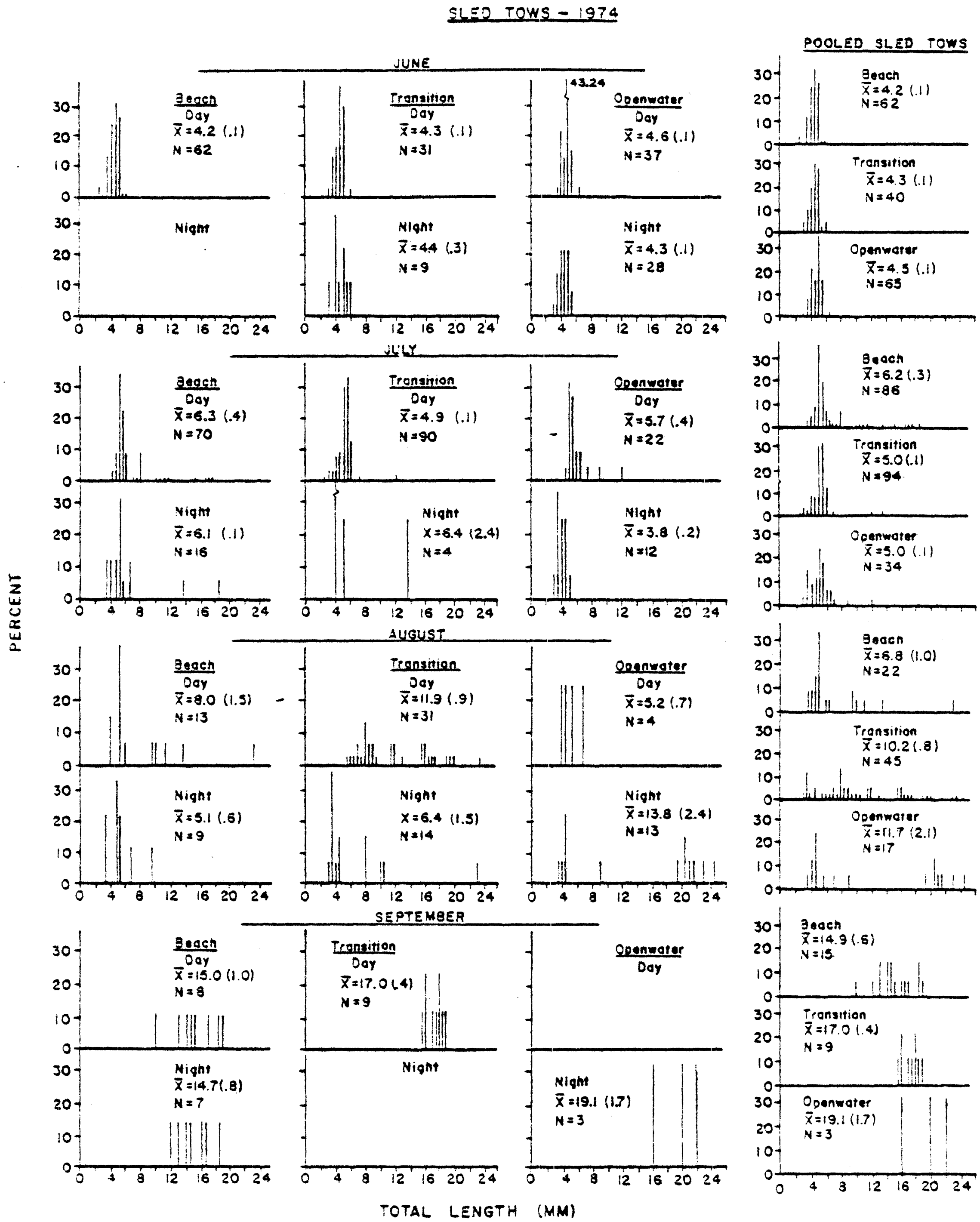

FIG. C8. Monthly length-frequency histograms for alewife larvae caught in sled tows during 1974 from Cook Plant study areas, southeastern Lake Michigan. Data were selectively pooled over day and night and by station as indicated. N = number of larvae used in the comparison, $\bar{X}$ = mean length of larvae. Standard error is given in parenthesis. Stations used in comparisons were: Beach - A, B, F; Transition (1.5-3 m) - P, N; Openwater (6-9 m) - C, D, G, H.

Vertical distribution -- Alewife larvae appeared to be distributed throughout the water column at beach stations in 1974. About the same numbers of larvae were collected in surface waters at beach stations as were captured in sled tows (Fig. C4). No consistent patterns were evident. Sled tow length-frequency data for beach stations (Fig. C8), as well as comparison of lengths of larvae captured at a given station with surface net tows and sled tows (Fig. C7) showed no difference in the lengths of larvae captured. We concluded that alewives of about the same size and densities were present in the entire water column at beach stations during June-August. There was a diel difference in the size of larvae present at beach stations (discussed in detail under diel distribution) where more larger larvae were caught during the day than at night.

Open water vertical distribution of larval alewives was similar to that observed for beach stations; larvae were present throughout the water column in varying quantities (Figs. C3 and C5). No consistent concentrations of larvae at any one depth occurred though bottom concentrations were generally the lowest. As previously discussed, there were consistently larger numbers of larvae collected at night than during the day, but no consistent patterns in depth distribution were evident. The potential for high entrainment of larvae is obvious when data for the 4- and 6-m strata (depths where most plant intake water is drawn) are examined. Larvae were almost always present in high densities in these strata.

Horizontal distribution -- Alewives in Lake Michigan were generally found in epilimnion waters; they were seldom caught in or below the thermocline. In addition, there was an inverse relationship between depth of water (beach to 21 m) and concentration of alewives. In 1973, during June for example, concentrations of alewives in beach station surface tows ranged from about 2000 to 10,000/1000 m^3, with most around 2000-3000/1000 m^3 (Fig. C2). At 6-m stations (C and G) in June, concentrations of alewives ranged from about 500 to 9900/1000 m^3; most were in the 2000-5000/1000 m^3 range (Fig. C3). At 9-m stations (D and H), concentrations were considerably less than observed at stations shallower, only about 100-6400/1000 m^3 with most less than 2000/1000 m^3. In June at 21-m station E, larvae were present at all depths sampled (day only), but in very low concentrations, from 40 to 670/1000 m^3. Water temperatures for the station E tows were 19.5 C at the surface and 7.2 C for the steptow. The single larva caught in the steptow was most likely taken in the warmer surface waters during net retrieval.

In July 1973, the pattern of reduced offshore alewife larval abundance with depth was even more pronounced. Beach station catches ranged from over 3500 to 26,800/1000 m^3; 6- and 9-m catches at stations C, D, G and H never exceeded 2600/1000 m^3 and 21-m station E day catches ranged between 0 and 480/1000 m^3. Water temperatures at station E varied between 17.9 C near bottom to 21 C in surface waters, and alewives were present throughout most of the water column.

In August 1973, alewives were still abundant in beach zone waters (500 to 14,300/1000 m^3), but had decreased drastically at 6- and 9-m stations where larvae were taken only in 6 of the 32 tows in low concentrations, all less than 900/1000 m^3. At 21-m station E, day catches at lower depths (steptow and 2 m) were zero, while the surface and 1-m tow contained 99 and 345 alewives per 1000 m^3, respectively.

The pattern of decreased abundance of larval alewives with increasing depth observed in 1974 was not as consistent as was found in 1973. On 11-12 June 1974, beach station catches were modest (from about 500-6600/1000 m^3) (Fig. C4); whereas, 6- and 9-m station catches generally were higher (up to 7500/1000 m^3, with almost half in the 2000-4000/1000 m^3 range) (Fig. C5). Catches at 21-m station E in June were low, with larvae only taken in the 20-m tow (34/1000 m^3) and 14-m tow (100/1000 m^3). Water temperature at 8 and 14 m was 12.8 C; surface temperatures were 15.5 C.

In July 1974, as was found in June, beach zone concentrations were quite high (up to 9500/1000 m^3), but 6-m stations had some tows with concentrations over 10,000/1000 m^3. Densities at 9-m stations were somewhat reduced, when compared with 6-m and beach zone stations, and 21-m station E in July had low concentrations of larvae, 232/1000 m^3 at 8 m and 88/1000 m^3 in the 14-m tow sample. Water temperatures were 22 C at 0 and 8 m, and 8.2 C at 14 and 20 m.

In August and September 1974, alewives were sparse (mostly less than 1000/1000 m^3) at all stations; no alewives were caught at 21-m station E except in the surface tow during September (35/1000 m^3 - water temperature 19.5 C).

Sled tow data for 1974 (Fig. C9) collected at all three beach stations (1 m) and stations P (1.5), N (3 m), C (6 m) and D (9 m) off the Cook Plant showed for 11-12 June that alewives were highly concentrated near the bottom during the day at beach stations and 1.5-m station P when compared with concentrations at 3- to 9-m stations. On 20 June and 25-26 June, too few larvae were caught in sled tows for valid statements, but data of 8-11 July showed the same pattern as observed on 11-12 June; large numbers were present at all beach stations and 1.5-m station P during the day. The remaining six periods for which data were available (two in July, three in August and one in September) showed about the same low concentrations of alewife larvae present on the bottom across all depths. No patterns with respect to depth, diel period or date were apparent.

Low numbers of alewife observed in sled (Fig. C9) and net tows (Fig. C4) taken on 25-26 June 1974 (period of near maximum abundance of alewives) was undoubtedly due to an upwelling. Temperature decreased from 17.6 C 2 days earlier to 9.8 C on 26 June. It appeared most alewives moved offshore with the warm-water mass.

Thus our data showed a strong tendency for alewife larvae to be concentrated in 1.5-m and shallower water. This pattern was most evident in

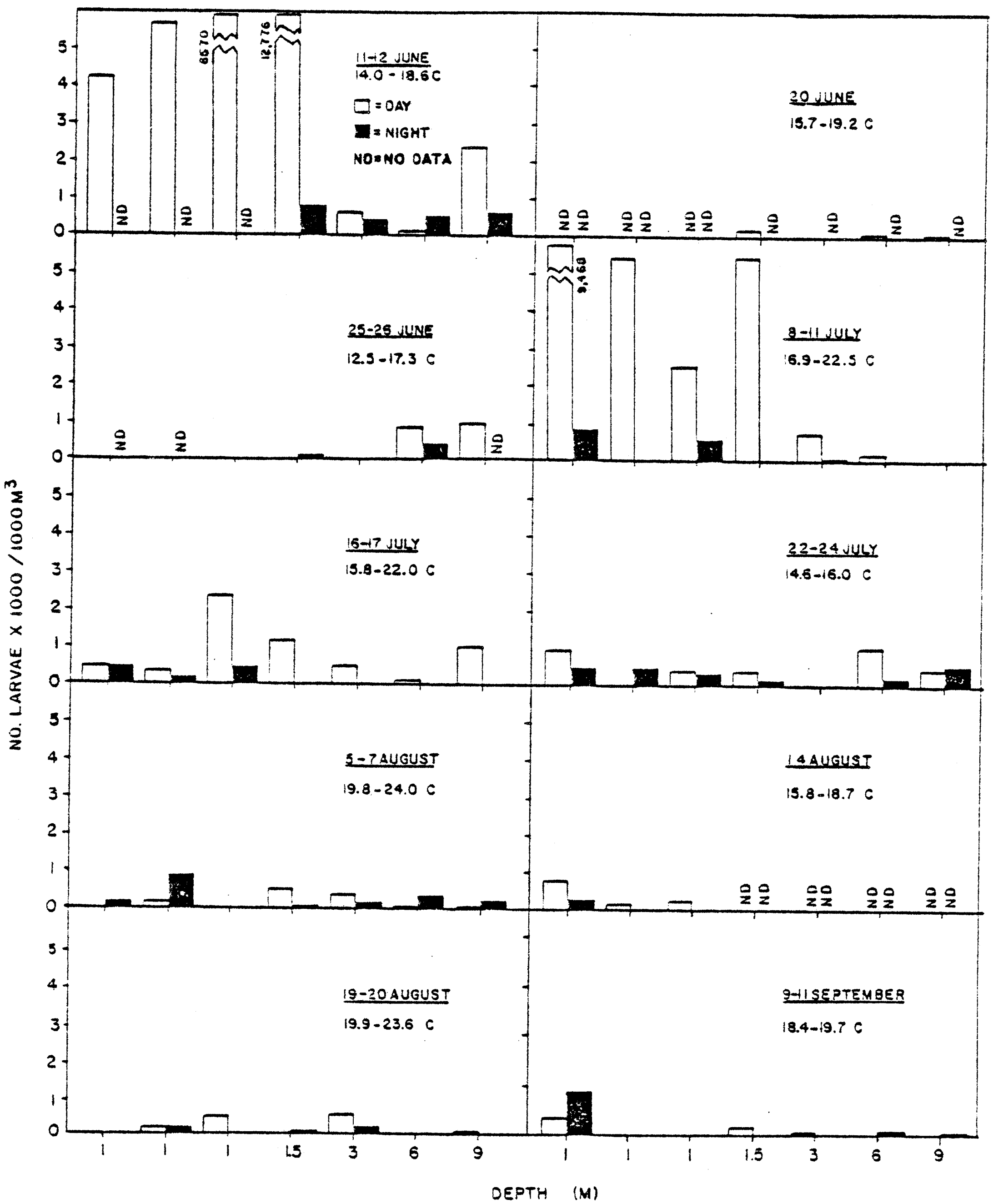

FIG. C9. Demersal distribution with depth of alewife larvae collected with a benthic sled during day and night sampling June-September 1974 at a transect of stations off the Cook Plant. Stations depicted are respectively: A, B, F, P, N, C, D, - see map, section B for further station descriptions.

1973 net tow comparisons; in 1974, alewife larvae tended to be abundant at all stations out to 9 m, with reduced abundance at 21-m station E. Sled tow data showed a more pronounced inshore abundance of alewives during two sampling periods in June and July 1974.

Length-frequency histograms -- All larvae collected were measured, so that along with densities, we had length data to help delineate relationships between day and night catches, station, and depth differences and ultimately to find out how seriously net avoidance by alewife larvae affected our conclusions. Because of the vast amount of length data from individual stations, depths and times, it was necessary to pool many of these factors to make more concise summary statements. One of the factors over which data were pooled was depth. To do this we ensured there were no differences with depth in the length of alewives captured by plotting for a typical station (D - 9-m Cook) the 1974 length-frequency distribution by diel period, date and depth (Fig. C10). In June, larvae were in the 4-6-mm range at all depths, both day and night. In July, larvae captured were more variable in occurrence and lengths, but no stratification occurred by a particular size group at a specific depth. In August, distribution of alewives was extremely spotty at station D, being most abundant in the 2-m night tow; few were present in any other tow depth samples. Again no patterns were evident, giving justification for pooling for more meaningful comparisons.

During June 1973, alewife larvae caught at beach stations during the day ($\bar{x}$ = 7.3 mm, N = 87) were larger than those caught at night ($\bar{x}$ = 5.1 mm, N = 82) (Fig. C6). This same pattern was repeated for July and August beach net tows in 1973, but only during August in 1974. Difference between years is believed to be related to the weather, as 1974 was a colder year than 1973 and larvae in 1974 grew slower than their 1973 counterparts. Thus in 1974 during June and July when no large size differences were observed between day and night catches of alewives at beach stations, most larvae were still small and newly hatched, and apparently not large enough to exhibit the offshore nocturnal movement seen with larvae in the beach zone during 1973.

In open water, during June 1973, there were no large differences between the mean lengths of larvae caught during the day and night (5.6 mm vs. 5.0 mm, respectively) (Fig. C6). This result is puzzling since densities of larvae caught during the night at all open water stations in June (Fig. C3) far exceeded the comparable day catch for most tows. Thus if net avoidance caused this difference in larval densities between day and night, as we think, we would expect to catch more larger larvae at night. Apparently, even this small size of alewife larvae (average size 5 mm; range 3-10 mm) can avoid plankton nets during the day to a great degree. Comparing mean length of alewives caught in the beach zone ($\bar{x}$ = 6.6 mm) with those caught in open water ($\bar{x}$ = 5.2 mm) showed that larvae in open water were slightly smaller than those collected in the beach zone (Fig. C6).

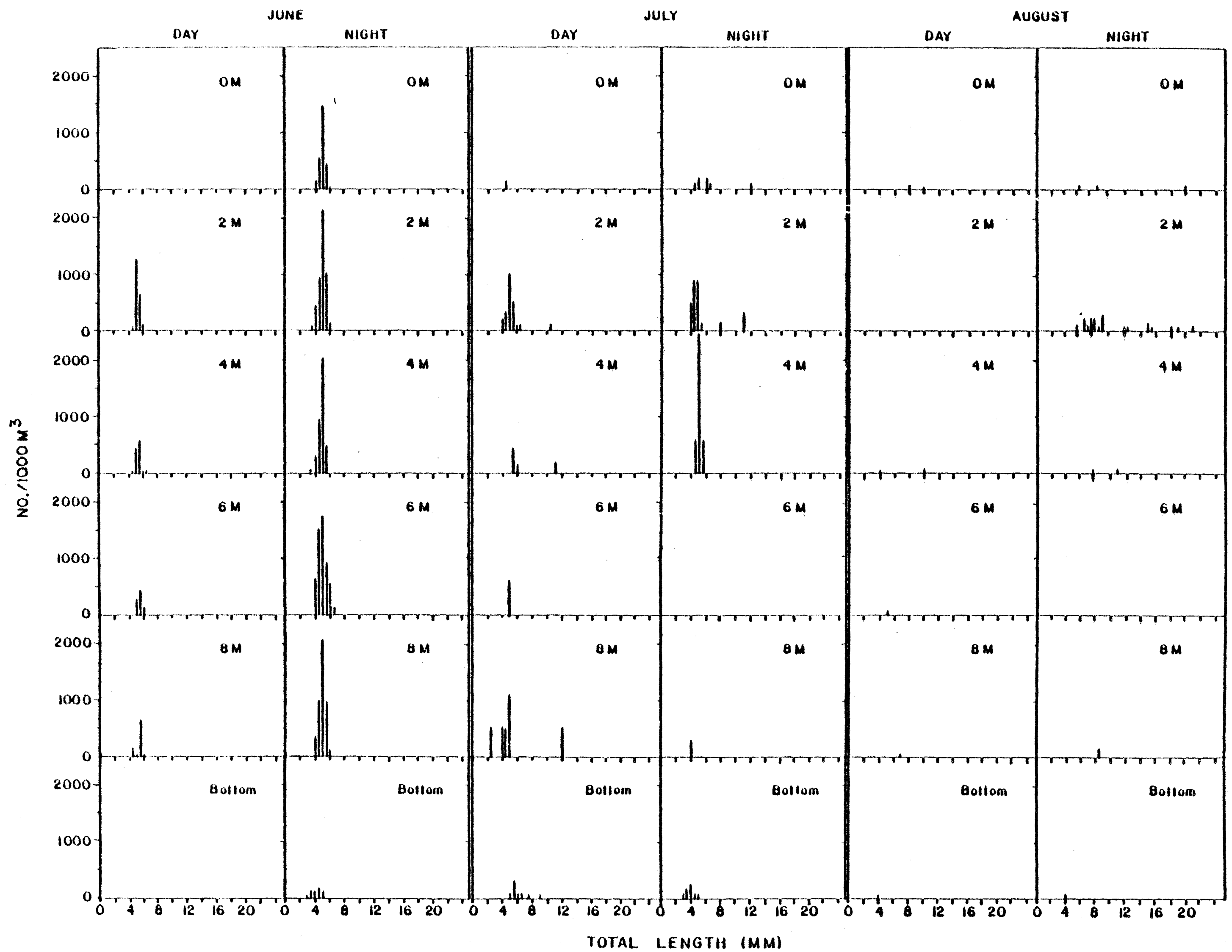

FIG. C10. A typical length-frequency histogram for alewife larvae captured during June-August 1974 at the various depth strata of station D (9 m - Cook), southeastern Lake Michigan. Bottom refers to sled tow data.

In July 1973, mean size of alewives caught during the day in the beach zone ($\bar{x}$ = 10.4 mm) was again larger than those caught in the respective night catch ($\bar{x}$ = 6.7 mm). The reverse was true for July open water catches where more and larger larvae were caught during the night ($\bar{x}$ = 8.4 mm, N = 173) when compared with day catches ($\bar{x}$ = 6.9 mm, N = 78). Again, as in June, alewives in the beach zone during July were on the average larger than those collected in open water.

In August 1973, the nocturnal offshore movement from the beach zone by alewife larvae was clearly shown as 131 larvae (unadjusted catch) were collected during the day ($\bar{x}$ = 11.8 mm) while only 19 were taken at night ($\bar{x}$ = 9.9 mm). The ability of alewives to avoid a net during the day makes this comparison even more dramatic, as the number captured during the day was undoubtedly an underestimate of the true numbers. Comparing beach length-frequency data with open water data for August, showed that beach zone waters contained much smaller larvae ($\bar{x}$ = 11.5; range 4-16 mm with a few 24-mm specimens) than were collected in open water ($\bar{x}$ = 21.5, range 16-25 mm). No reason can be given for this phenomenon.

Mean length of alewives (all net tows pooled during 1973) was 5.5 mm in June, 8.4 mm in July and 12.3 mm in August, reflecting growth of larvae over months. Since there is recruitment of new larvae every week, these means do not, as was true for some other species of fish which spawn over a short period of time, represent growth by one cohort of alewives.

In 1974, unlike 1973, few differences in mean length of alewives were found over habitat type or diel period (Fig. C7). As noted previously, 1974 was a colder year, and alewives captured in all habitats sampled with either net or sled tows were newly-hatched larvae averaging around 4.5 mm; none were over 7 mm. It is our belief, and these data substantiate it, that alewife this size are semi-planktonic and have little control over their movements. They are quite vulnerable to the vagaries of wind-induced currents and to entrainment, should they become part of the intake water used for cooling the condensers. Thus it is reasonable to expect these larvae to be essentially distributed in all habitats and to exhibit little net avoidance as the June 1974 larvae data showed.

In July, there were some differences in the average size of alewife larvae collected. In the beach zone, the same range of sizes of larvae were caught during the day and night (about 3-20 mm). However, more larger larvae were taken at night resulting in the mean length of night-caught larvae (8.1 mm) being greater than day-caught larvae (6.3 mm), which was contrary to results noted during all months of 1973 and August 1974. Alewives caught in the beach zone in July ($\bar{x}$ = 7.0 mm) were longer than those caught in open water ($\bar{x}$ = 5.2 mm), a finding consistent with past results, probably an actual difference between habitats. Alewife larvae caught in net and sled tows in July were similar in size.

In August 1974 at beach stations, day-caught alewives ($\bar{x}$ = 10.0 mm) were longer than those caught at night ($\bar{x}$ = 8.0 mm) which has been a

consistent finding supportive of the offshore nocturnal movement by longer alewife larvae. In open water larger larvae were caught at night than during the day while comparing mean length of alewives collected in the two habitats showed that about the same sizes of larvae were found at both beach and offshore stations. Length of alewives caught near the bottom (sled tows) was similar to length of those caught higher in the water column (net tows).

In September, no offshore nocturnal migration occurred at beach stations, since large larvae were caught during the night ($\bar{x}$ = 22.6 mm) and during the day ($\bar{x}$ = 19.1 mm) (Fig. C7). Many sizes of larvae (8-20 mm) were only caught during the day in the beach zone. In general, comparing data from available habitat types, about the same size larvae (around 16-19 mm) were found in the beach zone, open water and on the bottom.

Alewife larvae during 1973 grew faster than their 1974 counterparts, which was also true of YOY alewives (see SECTION B - Alewife). In 1973 during June, mean length of alewives caught in net tows was 5.5 mm, whereas 1974 larvae averaged 4.7 mm (Figs. C6 and C7). In July 1973, alewife larvae were 8.4 mm, while 1974 larvae lagged behind at 5.8 mm. By August this difference was even larger as mean lengths of alewives in 1973 and 1974 were, respectively, 12.3 and 9.3 mm. Because of avoidance exhibited by alewives, these mean lengths are not indicative of the mean length of YOY alewives in the area as perusal of our seine data for YOY alewives will quickly show. For example, 8.4 mm was the mean length of July 1973 larvae; while seines were collecting YOY up to 30 mm.

Mean density of alewives (data pooled over all 6- and 9-m stations and depths) was about the same in June 1973 (2376, SD = 2475) as was found in June 1974 (2437, SD = 2034). In July, densities in 1973 (637, SD = 701) were only a fourth as high as 1974 abundances (2404, SD = 2763). This disparity between years may be due to the warmer temperatures in 1973, allowing alewives to spawn earlier and grow faster than 1974 counterparts. Thus, 1973 alewife larvae, by July, had already passed through some of the high mortality stages which reduced their numbers. Because 1974 larvae were behind those of 1973, there were still large numbers of newly hatched larvae around that had not experienced the full span of mortality to which older larvae were exposed.

The most consistent trend observed with sled tow length-frequency data (Fig. C8) was that of the 12 comparisons between day and night made for the three habitat types (beach, transition - 1.5, 3 m and open water - 6, 9 m) over June through September; in 10 of the 12 cases more larvae (unadjusted numbers) were caught during the day than at night. Since approximately equal effort was involved in gathering both day and night data, and net avoidance by alewives during the day would tend to reduce numbers caught by the sled, we concluded that alewives were more concentrated near the bottom during the day than at night. Sled tow density data (Fig. C9) also showed highest concentrations of alewives on the bottom at most stations during the day rather than at night, but especially at beach and 1.5-m stations. Mean

size of alewives caught in sled tows during the day compared with those caught at night in June and July were about the same; no significant size segregation was apparent. In August, day-caught larvae were larger than night-caught larvae at beach and transition stations, but this pattern was reversed at open water stations. Sled tow data demonstrated a tendency in August and September for alewives to be of larger mean size, the further out from shore one proceeded (Fig. C8); whereas, in June and July, alewife larvae were about the same mean size in sled tows at all three habitats sampled.

It thus appeared that alewife larvae were exhibiting a tendency to be most concentrated near the bottom during the day when compared with night catches at the same stations. Generally the same size larvae were caught in both day and night sled tows, so no size segregation by diel period was involved. To further document this distribution pattern, abundance by depth over day and night at open water stations (Figs. C3 and C4) was examined but no evidence of increased abundance of alewives near the bottom during the day was observed. However, entrainment results for 1974 did show that more alewife larvae were caught during the night than during day for some months, which would support a pattern of increased activity at night in upper depth strata. In August 1974 and July 1975, more alewife larvae were entrained during the night than during the day (114 vs. 555/1000 m^3 and 32 vs. 114/1000 m^3, respectively - see SECTION D - RESULTS). However, during July 1974 and August 1975 more were caught during the day than at night (427 vs. 204/1000 m^3 and 39 vs. 29/1000 m^3, respectively). Since the strongest tendency for alewife larvae to be found near the bottom during the day was at inshore stations, this demersal diurnal habit may be less pronounced offshore (9 m) and not be strongly exhibited in entrainment results.

Potential entrainment impact -- Alewives are the most abundant larvae found around the Cook Plant during most of June through September. They were found in the beach zone and out to 21 m, they occurred throughout the water column and in general did not change their distributional patterns much over diel period. Thus, larvae were usually abundant in the vicinity of the intake structures (9 m) through most of the summer. As would be expected from these field results, alewives should be the most frequently entrained larvae and entrainment data (see SECTION D) confirm this conclusion. During July and August 1974 between 1.4 and 2.5 million alewives/24 h were entrained during Unit 1 operation. Most alewife larvae entrained were small, recently hatched individuals, which was also true of other species.

We believe that most species of larval fish are most susceptible to passive transport by currents for a critical period just after hatching. During this protolarval stage (which differs for different species of fish) they exhibit little directed movements and are transported largely by currents. Working with mackerel larvae in the Atlantic Ocean, Sette (1943) felt that drift was very important in dispersing the hatched larval fish. He divided larvae into two phases, an early passive phase and a later active phase. In the passive phase larvae were carried to wherever the

wind-induced currents brought them (up to 3.7 km/day), sometimes into their regular nursery grounds, but when they did not poor recruitment resulted that year. Sette divided his active and passive larval phase at about 8-10 mm, after which larvae developed fins and metamorphosed into a post-larval stage (metalarvae).

Most alewife larvae entrained were small, in the 3-10 mm range; however, some larger individuals were also collected. Since a considerably wider length range of alewife larvae were observed in field samples, the question remains whether these larger larvae are (1) entering the intake structure at all; i.e., what is their behavior once exposed to the intake current (maximum velocity is 0.39 m/s), (2) if they do enter the intake structure, are they avoiding our entrainment sampling pump? We expect to perform additional analyses to answer these questions. Finally, the question of what mortality alewife larvae experience in Lake Michigan must be answered. Entrainment of large numbers of larvae can be evaluated adequately only when survival rates are known. However no reliable estimates are available for the lake. Some marine work by Houde (1977) showed that total larval mortality for scaled sardine (Harengula jaguana) was more than 99.9% between the time of spawning and attainment of 15.5 mm standard length at 20 days of age. Clady (1976) found for yellow perch in Lake Oneida that total mortality (from egg to pelagic stage, 8 mm) varied from 81.6 to 98.4%.

Spottail Shiner --

Introduction -- Although spottail shiners were the second-most abundant fish in adult field collections during 1973 and 1974, spottail larvae appeared to be grossly underestimated in 1973 fish larvae tows, since few were collected. This led us to design a benthic fish larvae sled in 1974 to investigate a hypothesized demersal distribution of species seldom if ever captured in standard horizontally towed plankton nets. Since the exact depth at which spottails spawn was also unknown, sled tows were performed at all beach stations and at intermediate depths out to 9 m.

Spottail shiners are a common fish inhabiting large lakes and rivers. Some work has been done on adults in Michigan (see SECTION B, Spottail Shiner), but virtually nothing is known about the distribution of the larval stage. Since other adult cyprinids are rare in the area (49 emerald siners, 41 longnose dace and 28 carp were caught during 1973; whereas 20,681 spottails were collected), larval fish identification problems were minimized. Spottail shiners appear to be locally abundant in southeastern Lake Michigan. It is not known how spottail shiner populations reacted following the spectacular decline of the emerald shiner in the 1960s (Wells and McLain 1973) because of the alewife invasion.

Seasonal occurrence -- The first occurrence of spottail shiner larvae in 1973 net tows at beach and open water stations was on 19 June (Figs. C11 and C12). None were captured during May 1973. Spottails captured during the remainder of 1973 were caught only in July and August at beach stations. Highest concentrations at beach stations occurred during June 1973.

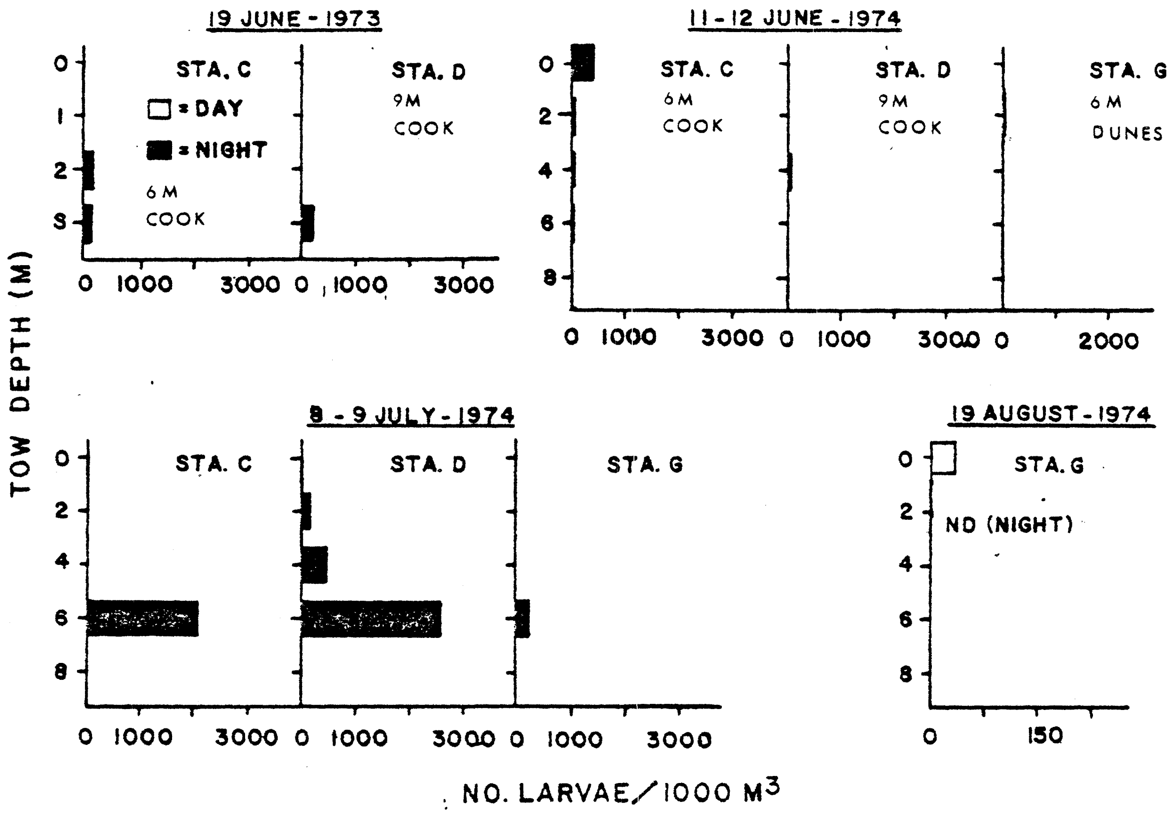

FIG. C11. Vertical distribution in no./1000 m^3 of spottail shiner larvae captured during day and night sampling in 1973-74 at Cook Plant and Warren Dunes openwater stations, southeastern Lake Michigan. ND = no data.

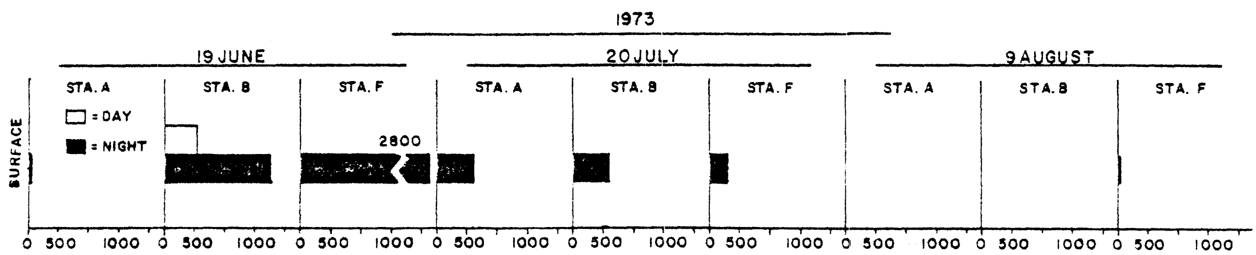

FIG. C12. Distribution of spottail shiner larvae in no./1000 m^3 during day and night sampling, June-August 1973 at Cook Plant beach stations. Each bar represents the mean of two observations.

In 1974, spottail shiner larvae were collected surprisingly early, on 13 May at two stations (P - 1.5 m, N - 3 m) in day sled tows--water temperature was 9.4-10 C (Table C1). Lengths of these larvae (5.0, 5.0, 5.1 mm) indicated they were recently hatched individuals. Newly hatched spottails that we cultured from eggs collected from the south intake structure while SCUBA diving on 26 July 1974 (Dorr and Miller 1975) ranged from 3.8 to 5.8 mm with a mean of 4.6 mm (N = 9). Mansuetti and Hardy (1967) list 5.0 mm as hatching length for spottails. The apparently anomalous early occurrence of spottail larvae in May is difficult to explain. They may be larvae which hatched in inland lakes or rivers and were then transported to Lake Michigan. An alternate hypothesis is that these larvae may be misidentified and could be some other cyprinid; however, J. J. Loos (personal communication, Academy of Natural Sciences, Philadelphia, Pennsylvania) verified our identifications.

Spottails (4.9 and 5.0 mm) were again caught on 1 June 1974 in a day sled tow at station N (3 m) when water temperature was 18 C. None were caught during day net and sled tows at beach stations at this time (no night tows were performed). However, on 4-5 June 1974, only 3 days later, spottails were common at all beach stations, both day and night with more being caught at night (Fig. C13). Lengths of larvae caught on 4-5 June ranged from 3.5 to 5.5 mm, again indicating they were newly hatched fish. Spottail larvae were common in every collection at beach stations from 4-5 June to 19 August in 1974 and some were taken at beach stations B (S Cook) and F (Dunes) on 9 September. Highest concentrations in surface and sled tow beach zone samples during 1974 occurred from 8 July through 19 August. Newly-hatched larvae were common during June and July indicating continuous recruitment through these months. Few larvae occurred at open water stations (Fig. C11), but one, 5.1 mm, was taken at station G (6 m - Dunes) during a day surface tow on 19 August 1974. Again, since this larva was newly-hatched, the apparent span of the spawning season for spottails during 1974 was from before 4-5 June to sometime before 19 August, roughly from June through July, a period of 2 mo. Larvae caught on 13 May were probably derived from outside Lake Michigan, and at any rate represented a small spawning occurrence. Peer (1966) inferred from his seining activities that spottail shiners in Nemeiben Lake, Saskatchewan finished spawning within 1 day. We have found spawning to occur over much of late spring and summer, with concentrated spawning during June. Scott and Crossman (1973) and J. J. Loos (personal communication, Academy of Natural Sciences, Philadelphia, Pennsylvania) have stated that spottails spawn over sandy or gravel shoals, which typifies the inshore zone of southeastern Lake Michigan very well.

Dorr (1974b) has documented spawning by spottail shiners in 1973 on top of the intake structure about 4-5 m off the bottom (9-m contour). Several females were observed to deposit eggs into the _Cladophora_, although subsequent fertilization by males was not seen. Adults captured by hand were ripe-running. The spawning activity was documented during a night dive on 17 June 1973. During June 1974, eggs interwoven among the periphytic algae (mostly _Cladophora_ growing on the intake structure) were collected by

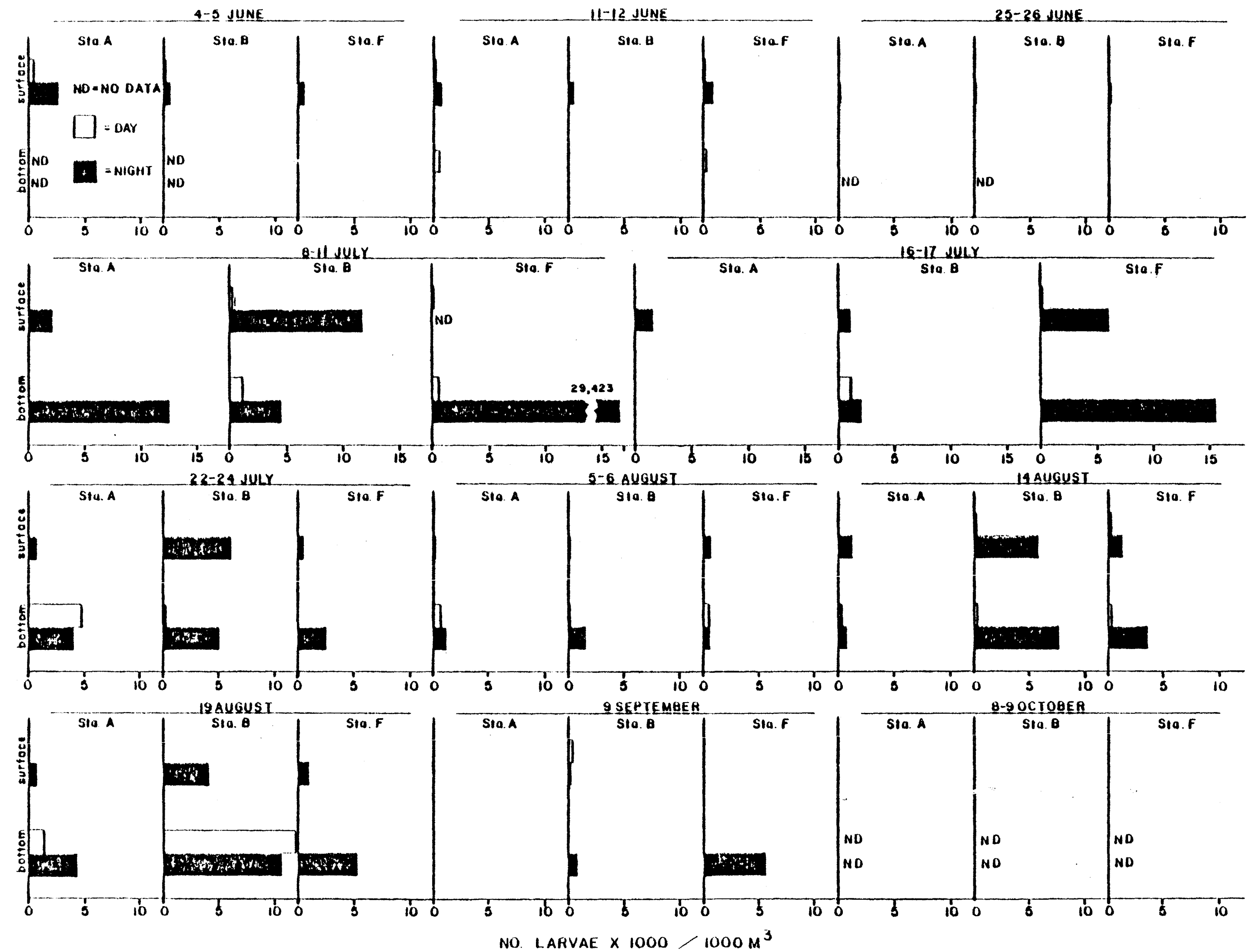

FIG. C13. Vertical distribution of spottail shiner larvae during day and night sampling, June-October 1974 at Cook Plant beach stations. Surface samples were collected in duplicate and the mean shown; only one tow was made with the benthic sled for bottom data.

divers, hatched in the laboratory and identified as spottail shiners (Dorr and Miller 1975). We believe the spawning observed at 9 m is atypical and represents opportunistic behavior by spottails utilizing a particularily favorable spawning substrate (attached algae on structure top). We inferred that most spawning must occur further inshore (in less than 3 m).

Diel distribution -- Examination of the available day and night collection data for spottail shiner revealed that most spottails were collected at night, a pattern that was generally consistent regardless of where (beach zone or open water) or how (net or sled tows) larvae were collected. We believe this phenomenon was wholly related to net avoidance. There were enough exceptions to the pattern; i.e., occasional large numbers caught during the day, to indicate that larvae were present at the sampling locations during day sampling, but that they were avoiding the net most of the time. Since we sampled vertically and horizontally with surface tows and sled tows, we are confident spottails did not migrate during the day to an unsampled area.

Further proof of the net avoidance hypothesis was that comparison of the mean length of larvae caught during the day and night at selected pooled stations (Figs. C14 and C15) showed that larvae caught at night were with one exception always larger than comparable day-caught specimens. Night samples also contained spottails with a much wider length range.

In 1973 beach station catches from June through August (Fig. C12), spottails were caught at night seven times in concentrations ranging from 120 to 2800/1000 m^3, while they were only caught once during the day (500/1000 m^3). In 1974 beach station collections (surface tows only), which were much more extensive than 1973 (Fig. C13), spottails in the period from 4 June to 9 September were collected 27 times at night and 9 times during the day. Mean concentration of these night samples was 1900/1000 m^3 ranging from 32 to 12,000/1000 m^3. It should be noted that 12,000/1000 m^3 was the highest concentration of spottails ever caught in any net tow that contained spottails during 1973-1974. Sled tow concentrations were higher. Day catches of spottails in 1974 occurred as noted only 9 times at beach stations (27 times at night) and mean concentration was almost 15 times smaller (120/1000 m^3) than comparable night tows, dramatic proof of spottail net avoidance during the day. Consideration of open water fish larvae tows (Fig. C11) showed that spottails were collected 15 times during 1973-1974; only one occurrence was recorded during the day and that was the lowest concentration.

Sled tow data at beach stations (Fig. C13) and for the 1.5- and 3-m transition stations (Fig. C16) also showed a preponderance of night-caught spottail shiners. The largest concentration of any larval species at any station was spottail shiners 29,000/1000 m^3 collected at night via the sled at station F on 8-11 July 1974; less than 200/1000 m^3 were observed in the comparable day sample. On only two occasions were more larvae caught during the day than at night, once on 22-24 July at beach station A (N Cook) and once on 19 August 1974 at beach station B (S Cook). More larvae were caught

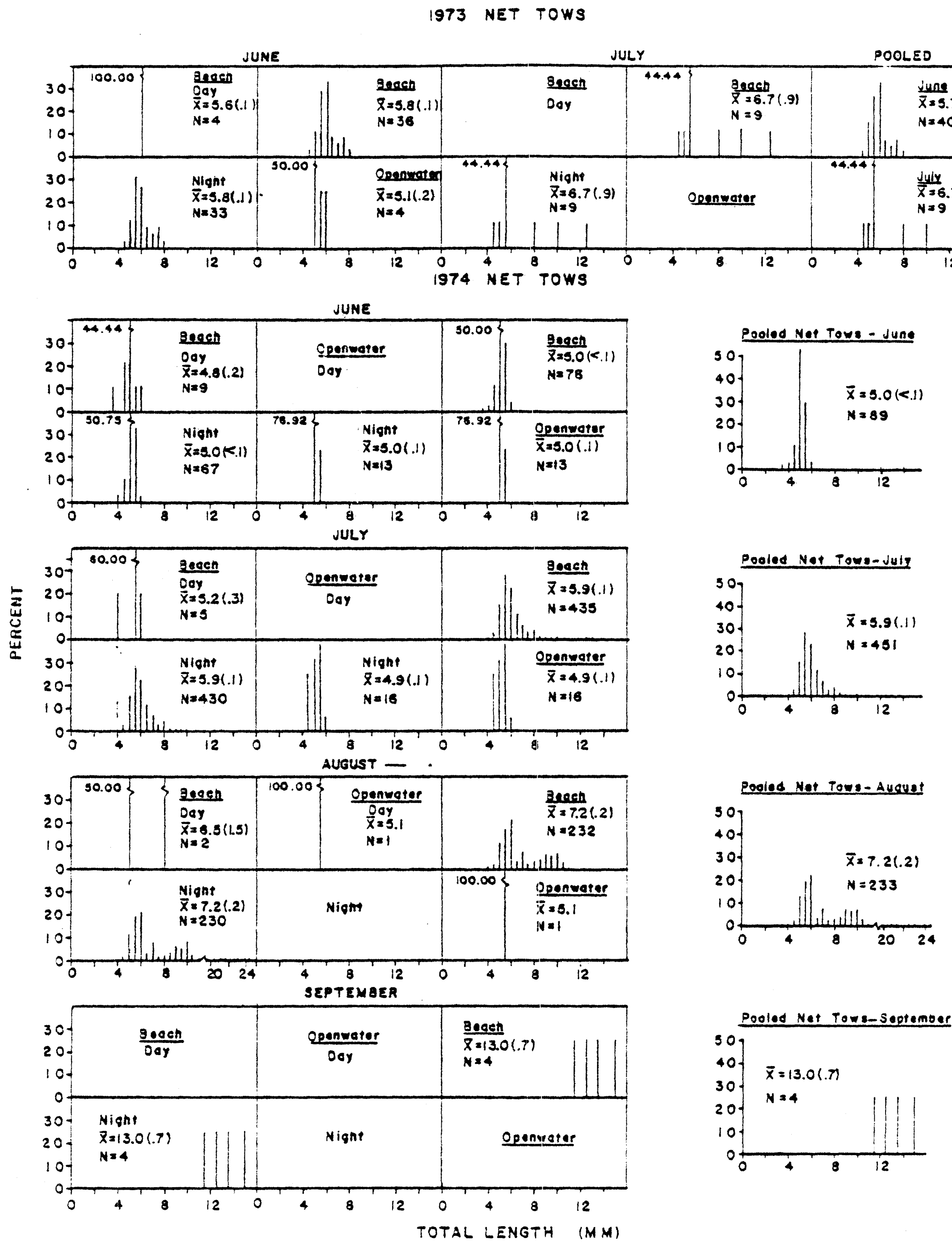

FIG. C14. Monthly length-frequency histograms for spottail shiner larvae caught in net tows during 1973-74 from Cook Plant study areas, southeastern Lake Michigan. Data were selectively pooled over day and night, station and depth as indicated. N = number of larvae used in comparison, $\bar{X}$ = mean length of larvae. Standard error is given in parenthesis. Beach stations included A, B, F, open water stations included C, D, G, H.

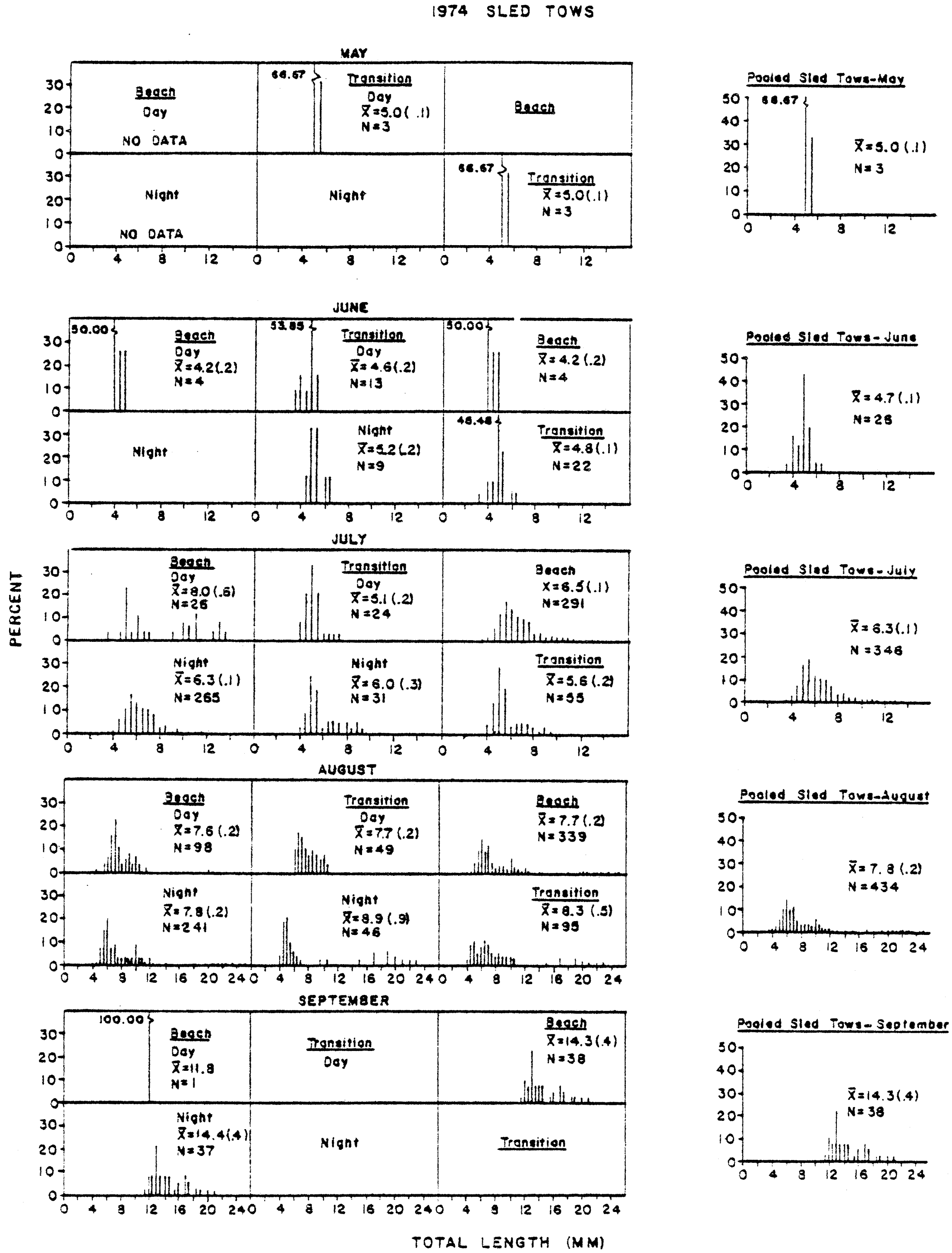

FIG. C15. Monthly length-frequency histograms for spottail shiner larvae caught in sled tows during 1974 from Cook Plant study areas, southeastern Lake Michigan. Data were selectively pooled over day and night and by station as indicated. N = number of larvae used in the comparison, $\bar{X}$ = mean length of larvae. Standard error is given in parenthesis. Stations used in comparisons were: Beach - A, B, F; Transition - P, N; Openwater - C, D, G, H.

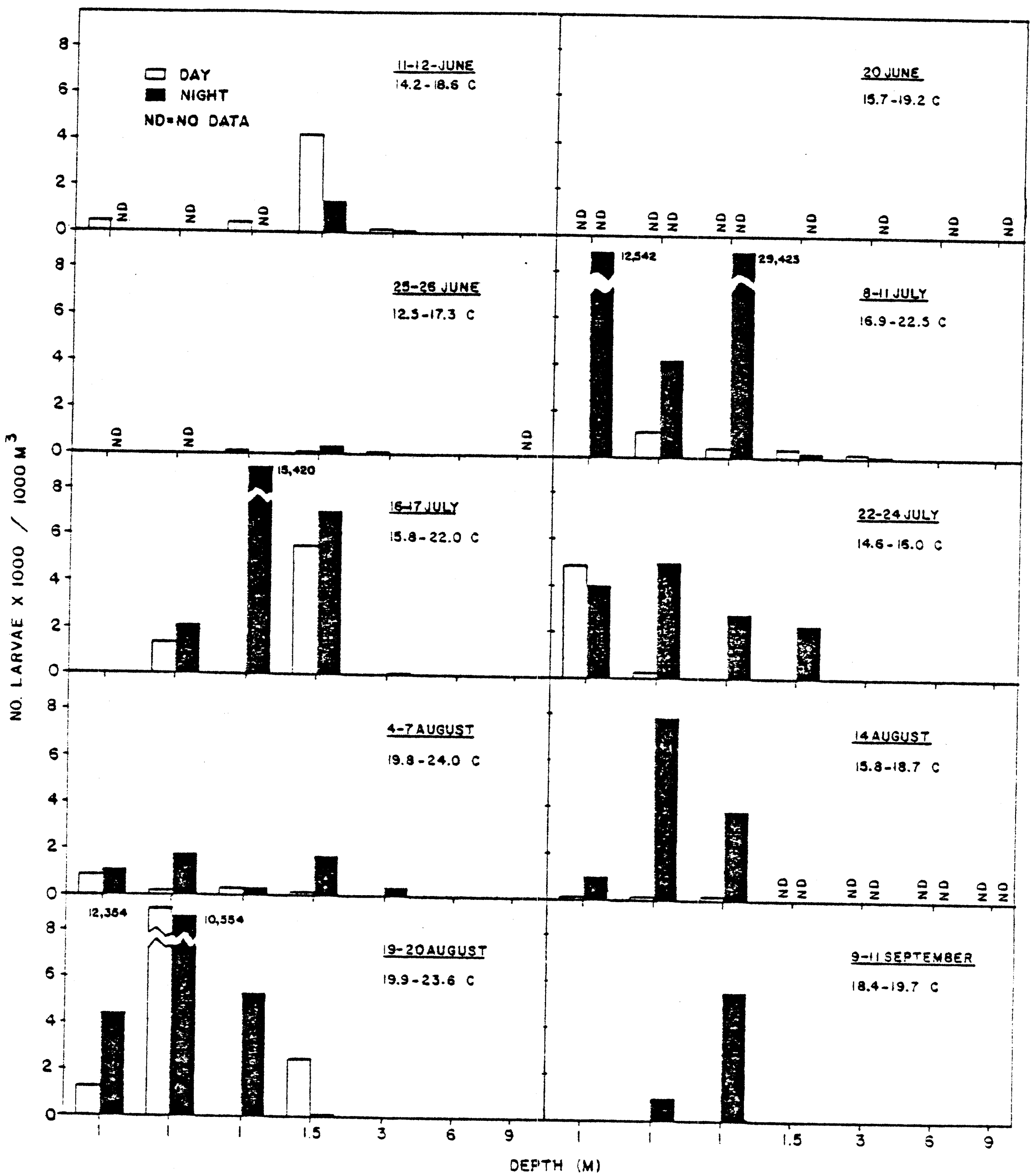

FIG. C16. Demersal distribution with depth of spottail shiners collected with a benthic sled during day and night sampling, June-September 1974 at a transect of stations off the Cook Plant. Stations depicted are respectively: A, B, F, P, N, C, D - See Fig. B1 for further station descriptions.

during the night, but whether spottails are more active during day or night must await further data analysis. One area of pursuit will be examination of larvae guts to establish day or night feeding.

<u>Vertical distribution</u> -- Distribution of spottails with water depth was somewhat confounded by a few larvae captured at open water 5- and 9-m stations and the preponderance of night-caught specimens, which indicates net avoidance and consequently low numbers of larvae collected during the day. Since the vast majority of spottail larvae were distributed inshore (3 m and shallower) and were apparently semi-demersal, occurrence at open water stations during 1973 and 1974 was somewhat puzzling. Since most of these larvae were in good physical shape, their presence was not attributed to weak or dying larvae transported from inshore waters though under certain conditions healthy larvae could be carried offshore. One other possibility is that these larvae are representatives of uncommon deepwater spawning (6 and 9 m) by spottail shiners. We believe most spawning occurred in 3-m water and shallower where larval abundance was ample evidence. Support for offshore spawning on substrates as noted previously, was given by Dorr and Miller (1975), who found spottail eggs in <u>Cladophora</u> growing on the intake structures on 17 June 1973. In addition, larvae collected from offshore stations in 1974 were always newly-hatched individuals as the mean length of larvae in 6- and 9-m June samples (Fig. C14) was 5.0 mm, in July 4.9 mm. Spottail larvae were most often caught in the 2- to 6-m depth ranges in the water column, but some were also caught in surface tows. More occurrences and higher concentrations of larvae were found at 6-m stations as opposed to catches at 9 m. Apparently some individuals were pelagic in the entire strata of the 6- and 9-m depth contours. However, these are a very small proportion of the total population.

Most spottails were found at inshore beach stations (Figs. C12 and C13) and were very abundant on the bottom. Highest concentrations of any tow or larval species were found for spottails in sled tows at beach stations in July and early August 1974--the highest being 29,000/1000 m^3 on 8-11 July at station F (Warren Dunes). Large numbers (15,000/1000 m^3) were found at station F on 16-17 July some days later, establishing the Dunes as a particularly important nursery area containing usually the highest numbers of spottails among beach stations. However, numbers over 10,000/1000 m^3 were also found at S Cook beach station B (19 August) and N Cook beach station A (8-11 July). Spottails were not confined to the bottom exclusively, as net tows at these beach stations (Fig. C13) often showed very high concentrations of spottails in surface waters. However, surface tow concentrations seldom exceeded sled tow concentrations. Interestingly, whenever bottom concentrations were high at a station, surface concentrations were also high.

<u>Horizontal distribution</u> -- Spottail shiners in Lake Michigan near the Cook Plant were concentrated on the bottom from 3 m to shore. Sled tow data from 1974 (Fig. C16) showed this conclusion dramatically. Spottail concentrations were generally highest at night at 1-m beach stations. Since spottails were abundant at all three beach stations, which are 7.5-km apart,

this horizontal distribution pattern (confined to shallow water <3 m) must be typical for spottails along most of the southeastern shore of Lake Michigan. As noted, concentrations in bottom tows at beach stations commonly ranged from 7000-29,000/1000 m^3 during times of maximum abundance, July-August 1974. These concentrations were unusually high compared to other species and point out the great abundance of larvae in the inshore waters. Highest concentrations occurred at night, which as discussed, was attributed to net avoidance. Concentrations at 1.5-m station P were usually less than 2000/1000 m^3 except on 16-17 July when 7000/1000 m^3 were collected. The 3-m station N was the deepest station at which spottails were collected on the bottom and concentrations were always very low, less than 100/1000 m^3. In view of these data, it is puzzling to find spottails in upper depths at the 6- and 9-m stations, an anomaly discussed already under Diel distribution. Spottails were first captured in sled tows on 11-12 June 1974--none were taken in sled samples during day beach tows on 1 or 4-5 June. On 25-26 June very few spottails were captured, but large numbers were taken from 8 July to 20 August. The low numbers of spottails collected on 25-26 June, despite some being collected before and large numbers after this data, may have been due to an upwelling. Water temperature plummeted from 17.6 C on 23 June to 9.8 C on 26 June the day sampling was conducted. Apparently this precipitous temperature decline disrupted spottail distributions. On 9-11 September, large numbers were still present (up to 5000/1000 m^3) at beach stations. By 24 September, larval spottails had moved to deeper water or were large enough to avoid the sled.

The persistent presence of spottails in the beach zone throughout summer, despite the currents, turbulence, turbidity and storms attests to their tenacity. This same robustness was apparent in the great amount of net avoidance exhibited by spottails.

Length-frequency histograms -- Interpretation of distribution data is facilitated when lengths of larvae caught are known. For spottails, total length of newly-hatched larvae is about 4.6 mm. Examination of our length-frequency data (Figs. C14 and C15) showed that spottails started hatching before 4-5 June (discounting the 13 May early occurrence) and continued through early August. This extended spawning period was not entirely predictable from previous work (Scott and Crossman 1973, Peer 1966). Maximum spawning occurred during late June.

To determine if there was spatial or diel segregation of sizes of spottail larvae, data were pooled first according to habitat showing day and night distributions. Then all data for a particular habitat were pooled to compare habitats (Figs. C14 and C15). For purposes of comparisons, habitats were beach (encompassing stations A, B, F), transition zone (stations P - 1.5 m, N - 3 m) and open water (stations C and G - 6 m, D and H - 9 m). Gear types (sled and net tows) were kept separate. Preponderance of more and longer larvae caught at night, when contrasted with day catches, dominated the previous discussions and continued to be displayed in the

length-frequency graphs. Not only were more larvae consistently captured at night, but considerably larger individuals were collected. Even though more larvae were occasionally caught during the day, seldom was the length range of day-caught larvae ever as wide as those caught at night. Again, the obvious explanation for these differences was net avoidance by larvae during the day tows. Considering all comparisons made, only once (July sled tows at beach stations) was the mean length of night-caught spottails ($\bar{x}$ = 6.3 mm, N = 265) smaller than length of spottails from the comparable day tows ($\bar{x}$ = 8.0 mm, N = 26).

Consideration of data on length of larvae caught by habitat type (Figs. C14 and C15) showed that for 1973-1974 net tows, larger larvae, as might be expected, were caught in the beach zone than in open water collections. It may be that larvae caught at 6 and 9 m were either newly hatched larvae contributed from miscellaneous spawnings in deeper water, or weakened larvae that drifted out to deeper water from the beach zone.

In June and August 1974, larvae caught by sled in the transition zone were longer than sled-caught larvae in the beach zone. However this pattern was reversed in July, the month of maximum abundance. Reasons for these differences remain obscure.

A similar confounded pattern was found when all 1974 data for a particular month and gear were pooled (Figs. C14 and C15). No larvae were collected in May net tows; mean length of sled-caught specimens was 5 mm (N = 3). In June, net tows collected slightly larger larvae ($\bar{x}$ = 5 mm, N = 89) than were collected in sleds ($\bar{x}$ = 4.7 mm, N = 26), though differences were small. These were mostly newly-hatched larvae. In July, the month when maximum numbers of spottails were collected, larger individuals were taken in sled tows than in net tows ($\bar{x}$ = 6.3 mm vs. 5.9 mm). This pattern of larger larvae in sled samples persisted for the remaining months of August and September. Perhaps newly-hatched larvae reside more in the upper strata than the older cohorts, they were more susceptible to current transport or the sled was more efficient in catching larger larvae.

Net and sled tows collected only a portion of the available spottail shiner larvae population. The largest mean length of larvae was recorded in September 1974 at 14.3 mm (SE = .4, N = 38). Young-of-the-year spottails were first seined in 1973 at 20-30 mm in July (see SECTION B, Spottail Shiner) -- our July mean larvae length in net tows was 6.7 mm, N = 9 (Fig. C14). In August, YOY spottails in seines were 20-50 mm with a modal length of 40 mm. Their length range increased to 30-60 mm in September 1973 and was 30-70 mm by October. As noted previously from our larvae data, and here corroborated by a wide range in YOY lengths, a prolonged (at least 2 mo - June, July) spawning period was indicated.

Comparisons of length between years (Fig. C14) showed that, as noted for other species, larval spottails grew faster in 1973 (a warmer year) than in 1974 (see SECTION B for more details). Comparing June 1973 net tows with June 1974 showed mean lengths to be respectively 5.7 mm, N = 40 and 5.0 mm,

N = 89. For July, mean length of 1973-caught spottails was 6.7 mm, N = 9, while in 1974 mean length was only 5.9 mm, N = 451. Comparable 1974 sled tow mean length for spottails taken in July (Fig. C15) was 6.3 mm, N = 346. Considering the aforementioned bias introduced into these larval data, seine data as used in SECTION B, provided much better documentation of year to year differences in growth among YOY and larval spottails.

Potential entrainment impact -- Based on the almost exclusive inshore demersal distribution of spottail shiner larvae, entrainment of spottails is expected to be minimal. However, because of the sporadic occurrence of spottails during June-August at open water 6- and 9-m stations, some entrainment of larvae in low numbers was expected. This was borne out by 1974 entrainment results (see SECTION D) which showed that spottails were entrained three times, twice in August at night (287/1000 m^3) and once during November also at night (14/1000 m^3). These data certainly suggest that any water intakes in Lake Michigan to be located in areas of spottail occurrence should be well beyond 3 m to avoid entraining large numbers of spottail larvae.

Rainbow Smelt --

Introduction -- Another introduced marine species, the rainbow smelt is still making adjustments to the freshwater environment and interacting with other species in Lake Michigan. First entering Lake Michigan about 1922 (MacCallum and Regier 1970) smelt spread rapidly and now are one of the dominant species in the lake. In our adult catches at Cook they ranked third behind the ubiquitous alewife and the spottail shiner. Our recent data (1975-1977) and other studies show that smelt are now in a period of decline in southeastern Lake Michigan. Because they spawn only once during a brief period in the spring, working with larval distribution and growth data is made somewhat easier. Very little is known about the distribution of larval smelt in Lake Michigan except for the work of Wells (1973, 1974) and a number of power plant studies around the lake.

Seasonal occurrence -- Rainbow smelt spawn at night when lake water temperature reaches about 10 C (Jude et al. 1975, Scott and Crossman 1973) which usually occurs in April or May in the southeastern part of Lake Michigan. At that time or slightly prior to it, adult smelt begin to migrate inshore at night in search of streams or shore areas for spawning. We believe most spawning around the Cook Plant occurs along shore in the beach zone area. Other investigators have also found this for smelt in a Maine lake (Rupp 1965) and in Crystal Lake, Michigan (Lievense 1954) where smelt were first introduced.

First observation of larval smelt in the study area occurred in the open water collections of 26-29 April 1973 when water temperature ranged from 6.2 to 7.7 C (Fig. C17). Numbers caught ranged from 0 to 1214/1000 m^3. No smelt however were taken at beach stations sampled earlier on 13-18 April (Table C2). Later, during the 15-18 May 1973 sampling period, smelt were collected in modest numbers (253-296/1000 m^3) only at beach station A (N Cook) and at

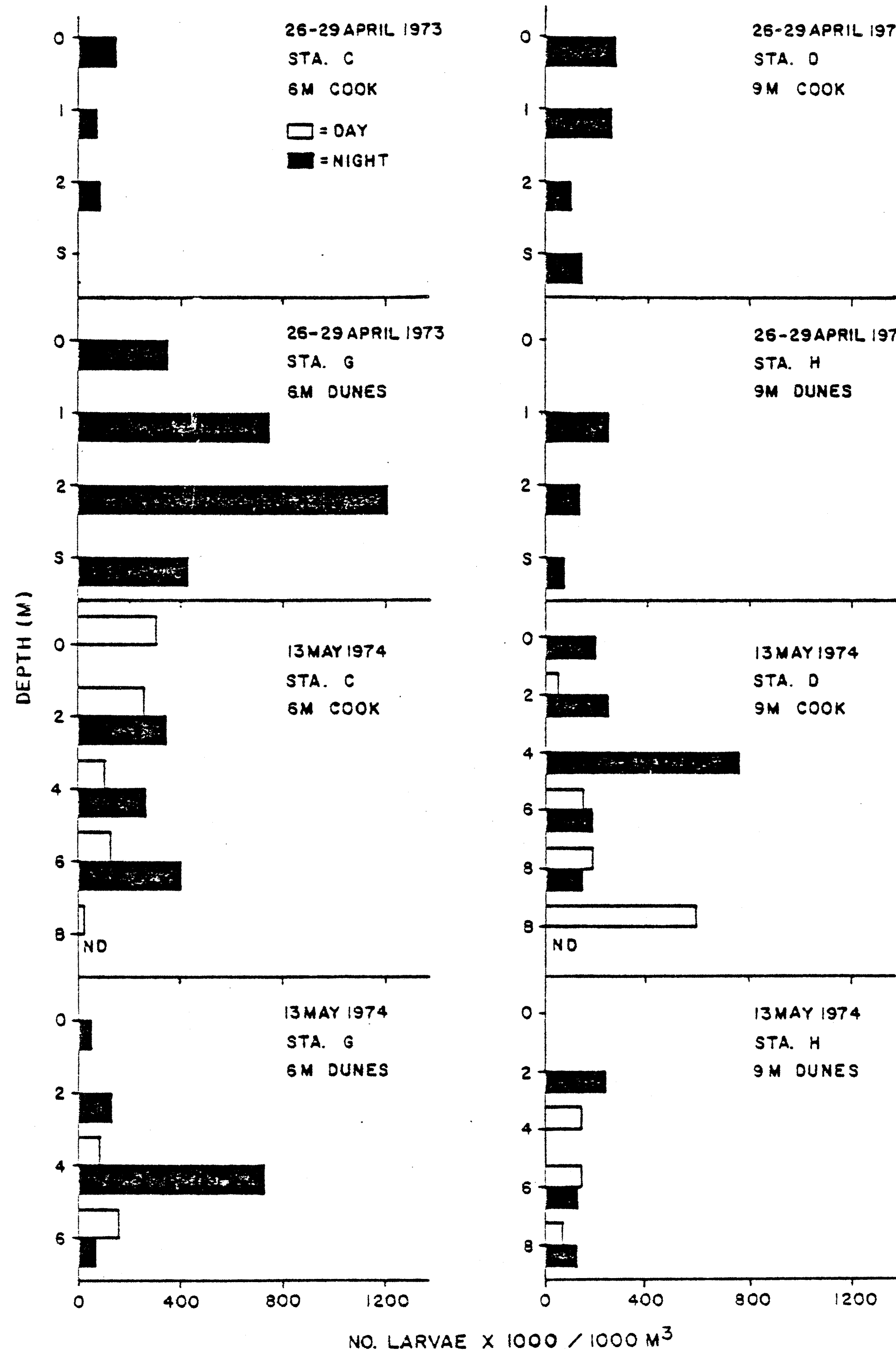

FIG. C17. Vertical distribution in no./1000 m^3 of rainbow smelt captured during day and night sampling in 1973-74 at Cook Plant and Warren Dunes openwater stations, southeastern Lake Michigan. B = sled tow data for the bottom, S = steptow - see METHODS for an explanation. ND = no data.

two open water stations, 71/1000 m^3 at the 6-m Cook station (day - 1-m tow) and 85/1000 m^3 at the 9-m Cook station (night - surface tow). This was the last time during 1973 that larval smelt were collected in net tows in any numbers at beach and openwater stations. One larva (17.6 mm) was collected during June (Table C2) at night at beach station B. Wells (1974) in his day larval fish collections off the Cook Plant on 3-6 May 1973 found high numbers of smelt (from 76-541/1000 m^3) in the 12 tows at all depths he performed at 5.5- and 9.2-m stations. Modest numbers (0-228/1000 m^3) were still present during his subsequent visit to those stations on 17-24 May, when water temperature varied from 10.3-11.8 C.

Table C2. Mean number of rainbow smelt larvae (no./1000 m^3) caught during the day and night in April-May 1973-1974 at beach stations in the Cook Plant study area, southeastern Lake Michigan. All larvae were collected in surface tows.

Date	Water Temp. (C)	STA A - N Cook Day	STA A - N Cook Night	STA B - S Cook Day	STA B - S Cook Night	STA F - Dunes Day	STA F - Dunes Night
14-16 MAR 73	8.0-10.0	0	0	0	0	-	-
13-18 APR 73	7.5- 9.9	0	0	0	0	0	0
17-18 MAY 73	10.7-12.5	0	0	0	0	0	0
19 JUN 73	22.0-24.5	0	0	0	126	0	0
29 JAN 74	0.4	0	-	0	-	0	0
6-15 MAR 74	3.5- 6.2	0	0	0	0	0	0
3 APR 74	10.2	0	-	0	-	-	-
9 APR 74	5.5	0	-	0	-	-	-
18-20 APR 74	7.4-12.0	0	0	0	0	0	0
24 APR 74	11.0	0	-	-	-	-	-
2-3 MAY 74	9.5-13.0	106	2958	82	215	0	0
8-9 MAY 74	8.0- 9.2	658	222	303	278	-	-
15-17 MAY 74	11.1-12.7	0	446	53	220	302	792
22 MAY 74	12.0	0	-	416	-	-	-

In 1974, beach zone stations were sampled more often to more closely pinpoint exact arrival time of smelt larvae in the beach zone. No smelt were taken in the beach zone or at open water stations prior to 24 April 1974, despite the fact that optimum temperature for spawning was recorded some days before, notably on 3 April. On 2-3 May 1974 smelt larvae were first noted in large numbers at beach stations A and B (N and S Cook) during both day and night. Numbers were quite high (2958/1000 m^3) in the station A night samples, indicating spawning had occurred somewhere in the immediate area anywhere from 2 wk prior (Bailey 1964 - hatching time for Lake Superior smelt eggs) to 19 days prior (McKenzie 1964 - Miramichi River smelt hatching

time when temperatures were 9-10 C). Smelt larvae we raised hatched in 19 days at 7 C. That would establish 12-17 April 1974 as an approximate time when these smelt eggs were deposited. Smelt larvae were found subsequently in the beach zone tows of 8-9 May, 15-17 May and 22 May 1974 (Table C2). Large numbers of smelt larvae were also found at all stations both day and night and at almost all depths sampled on 13-14 May 1974. It thus appears that for the last 3 yr for which data are available (1972-1974) smelt larvae were present in the area during late April and all May. In 1972, Wells found smelt most abundant on 27-28 May or sometime before. For 1973, we found smelt abundant on 26-29 April; Wells (1974) found them common on 3-6 May. By 15-18 May 1973 (our data) and 17-24 May 1973 (Wells' data) numbers of smelt larvae were already declining, probably due to net avoidance by larger larvae. For 1974 our data indicated 2-14 May as the period of maximum abundance of larvae. Higher concentrations of smelt larvae were present during 1973 than in 1974. More adults in spawning condition were also taken in 1973 seine samples at beach stations than were found in 1974 seine samples. The somewhat earlier appearence of smelt larvae during 1973 when compared with 1974 can be attributed to 1973 having an earlier, warmer spring and on the average higher water temperatures. A more detailed discussion of temperature differences between years and its effect on fish distribution and behavior can be found in SECTION B - General Diversity and Distribution of Fish Species.

Both adult smelt and larval concentrations have declined from 1973 through 1977, based on examination of preliminary data summaries. Reasons for the decline remain obscure.

Diel distribution -- Analysis of the 26-29 April 1973 larval smelt data for open water 6- and 9-m stations (Fig. C17) showed that, despite equal fishing effort for the day and night, no larval rainbow smelt were found in samples collected during the day. This is strong evidence supporting a diel vertical migration where smelt were on or near the bottom during the day and in upper waters at night. It should be emphasized however that 4 days after our field collections, Wells (1974) collected high numbers of smelt off the Cook plant during the day at two of the stations we had occupied previously. Our day samples were collected on 26 April and due to an impending storm, night samples were collected 3 days later on 29 April, which may have been the first occurrence of newly-hatched smelt. Despite Wells' contradictory evidence, our 1974 open water and sled tow data (Fig. C17, Table C3) generally indicated that smelt larvae resided on or near the bottom during the day and then migrated up to surface waters at night. A rather high number of smelt - 1202/1000 m^3 (the second highest recorded for any type tow made in 1973-1974 that contained smelt) was found in the day sled tow sample collected at the 9-m Cook station (D) and 45/1000 m^3 were found at station C (6 m - Cook) on 13 and 8 May, respectively.

Entrainment samples during May 1974 (see SECTION D) also corroborated this finding as day catches were lower than night catches, a reflection of smelt being on or near bottom during the day and at night migrating higher in the water column, apparently becoming more susceptible to being entrained.

Table C3. Date, station, diel period, water temperature and no./1000 m^3 of rainbow smelt larvae caught in benthic sled tows during 1974 in the Cook Plant study area, southeastern Lake Michigan. Only tows containing smelt larvae are given. D = day, N = night.

Date	Station	Diel Period	Water Temp. (C)	No./1000 m^3
8 MAY	C - 6 m Cook	D	9.2	45
8 MAY	D - 9 m Cook	D	9.0	1202
13 MAY	P - 1.5 m Cook	D	9.2	298
26 JUN	C - 6 m Cook	N	13.0	61
26 JUN	P - 1.5 m Cook	N	13.0	344
10 JUL	N - 3 m Cook	N	19.0	57
11 JUL	A - 1 m N Cook	N	20.2	380

Other support for a diel migration was that concentrations of smelt during April 1973 at the four open water stations (all depths) during the night averaged 270 ± 320 (SD) with a range from 0 to 1214/1000 m^3; none were caught during the day. In 1974, May night samples averaged 220 ± 220 (SD) with a range from 0 to 785/1000 m^3; during the day the average number of smelt was 100 ± 97 (SD) with a range from 0 to 309/1000 m^3.

Trends of diel depth distribution in 1973-1974 (Fig. C17), particularly station D, 9 m Cook, also showed that smelt were common in the lower depths during the day and more frequent in upper water at night. Preliminary examination of 1975-1976 data showed that first, very few smelt larvae were collected in 1975-1976 (25 in 1975 and only 7 in 1976), supporting the general belief discussed earlier that smelt may be declining in abundance. Second, of the only two stations where enough smelt were captured to identify patterns (stations C and R - 6-m Cook stations during 1975), one clearly exhibited a pattern of smelt larvae remaining near the bottom during the day and migrating to the surface at night, while this pattern was more ambiguous at the second station; day samples contained more larvae at the surface than comparable night tows. Wells (1973) noted for his Lake Michigan smelt samples for 1972 collected during the day, that most smelt were at depth strata of 2 m or deeper. For 1973 data (Wells 1974), he stated that smelt did not show a strong depth preference during the day, except they tended to avoid the surface. Work by Ferguson (1965) established that adult smelt in Lake Erie exhibited a diel vertical migration dispersing from their daytime residence on the bottom to a habitation of epilimnetic waters at night.

Vertical distribution -- Vertical distribution of smelt larvae has been discussed generally under diel distribution. Since there appears to be a difference between the day and night distribution they will be discussed

separately. During the day smelt were generally found near the bottom at open water stations, and sometimes in large numbers. As noted, none were taken during the day in April 1973. In 1974, however some smelt were captured during the day at station C (6 m Cook) at the surface (309/1000 m^3) and at 2 m (235/1000 m^3), but the remaining three stations (D, G, H) showed that most smelt during the day were found at the 4-m depth strata or lower. At night, smelt were generally found at intermediate or higher strata in the water column, though some were caught in the lowest depth at all stations (except one, station C, 1973) where horizontal tows were taken.

Horizontal distribution -- Smelt spawning in the beach zone, suggested by beach seine data, was confirmed by first occurrence and abundance of larval smelt at beach zone stations, particularly during 1974 on 2-3, 8-9, 15-17 and 22 May (Table C2). Smelt larvae migrated offshore later and were common at the 6- and 9-m contours. They appeared to remain there throughout summer and early fall, since YOY were common in our trawl catches during these seasons. YOY smelt were first recruited to trawl hauls at 6- and 9-m stations in August at a modal length of 40 mm. A growth curve for YOY smelt and discussion of YOY and adult smelt can be found under SECTION B - Rainbow Smelt. Support for inshore distribution of smelt eggs and newly hatched larvae can be found in Rupp (1965) who stated that smelt in a Maine lake never spawned deeper than 0.5 m despite extensive checks via SCUBA out to 6 m of water. The 21-m Cook Plant station was not occupied until June of both 1973 and 1974, so that the offshore distribution of smelt larvae during April-May beyond 9 m must await analysis of data from subsequent years. However, 1975-1976 data did indicate that a few smelt were distributed out to at least 21 m. None were taken at station E (21 m - off Cook) in May 1975. In May 1976, though, one smelt was collected from the night surface tow at station E and one was also observed in the 1976 day, 14-m tow at station W (21 m - off Warren Dunes).

Sled tow data (Table C3) showed that during peak larval abundance large numbers of smelt were often found on the bottom during the day at offshore 6- and 9-m stations. Unfortunately during April to May no sled tows were performed at any beach station, but modest numbers (298/1000 m^3 Table C3) were found at the 1.5-m Cook station P during May. These data showed that smelt were common on the bottom from at least 1.5 m out to the 9-m contour. Subsequent sled tow captures of smelt were made during the night on 26 June (stations C - 6 m and P - 1.5 m) and on 10-11 July at stations N - 3 m Cook and A - 1 m N Cook. These smelt were the only YOY specimens collected during June and July in either plankton net tows or trawl hauls and established the presence of YOY in the same general area (3-9 m) as was found earlier for larvae. Apparently smelt this size during June-July were too active (or on the bottom) to be caught with our plankton nets and too small for our 1.3-cm mesh trawl cod end interliner. As noted we caught large numbers of 40-mm smelt in the trawl starting in August.

Length-frequency histograms -- In order to examine the spatial and temporal segregation by length of smelt larvae, it was necessary to pool data from different depth tows at a given station. A typical

length-frequency distribution for larval smelt at an open water station is presented in Fig. C18. As can be seen, about the same size smelt larvae were caught at each depth stratum both day and night. Lack of size segregation, then, justifies pooling depths and stations to determine if beach zone vs. offshore or day vs. night differences existed in size of larval smelt captured. For April 1973 and May 1974, the range in total length of larval rainbow smelt was almost identical, being respectively 4.1-7.1 mm ($\bar{x}$ = 5.8) and 4.5-8.0 mm ($\bar{x}$ = 6.0) (Fig. C19).

Newly-hatched rainbow smelt larvae reared in our lab from eggs and milt taken from adult specimens caught during 1974 in Lake Michigan averaged 5.1 mm; McKenzie (1964) gave 5 mm for Miramichi River stocks.

Unlike species such as yellow perch which exhibited considerable net avoidance at larger sizes, smelt larvae greater than 8 mm were taken, although in low numbers in later months - all in sled tows. On 19 and 26 June 1974 smelt (15, 16.5 and 18 mm) were captured. On 10-11 July two more 22- and 25-mm smelt were taken. As noted, many were recruited to the trawl in mid-August at a modal length of 40 mm.

Comparing the mean length of smelt caught during the day and night at 1974 open water stations (Fig. C18), slightly larger smelt larvae were caught at night ($\bar{x}$ = 6.4, N = 67) than were collected during the day ($\bar{x}$ = 6.1, N = 35). This phenomenon may be related to daytime net avoidance by longer larvae or perhaps the newly hatched younger larvae resided more often on the bottom and did not participate in nocturnal upward migrations to the degree the older cohorts did. No difference in mean length between day and night catches at beach stations was found during 1974, which supports the earlier contention that newly hatched larvae (with low or no net avoidance capability) were first common in the beach zone then migrated offshore. Consideration of the beach vs. openwater comparison in May 1974 also corroborated this hypothesis as mean length of larvae taken in the beach zone was 5.6 mm, whereas mean length of larvae caught at 6- and 9-m stations was 6.3 mm. This comparison was unchanged when only beach-caught larvae from 15 May were used (open water data were collected on 13-14 May).

Sled tows in 1974 seemed to be sampling the same sizes of larvae as were sampled by plankton nets at beach and open water stations. Sled-captured smelt larvae in 1974 were slightly smaller ($\bar{x}$ = 5.8 mm) than those caught in upper water net tows where mean length of larvae was 6.0 mm.

Potential entrainment impact -- Entrainment potential for rainbow smelt is expected to be high during their period of peak abundance which can extend up to 1 mo. Because larval smelt occupy the depth contour of the intakes (9 m) during both day and night and occur at intermediate strata in the water column (4-6 m at the 9-m depth contour from where most water is drawn), they will be vulnerable to entrainment for 24 h per day during their early life. The Cook plant vicinity is not unique as a nursery area as undoubtedly the entire shoreline, where smelt are common and reproduce, serves as a nursery ground for smelt (see Wells 1973, 1974). After smelt

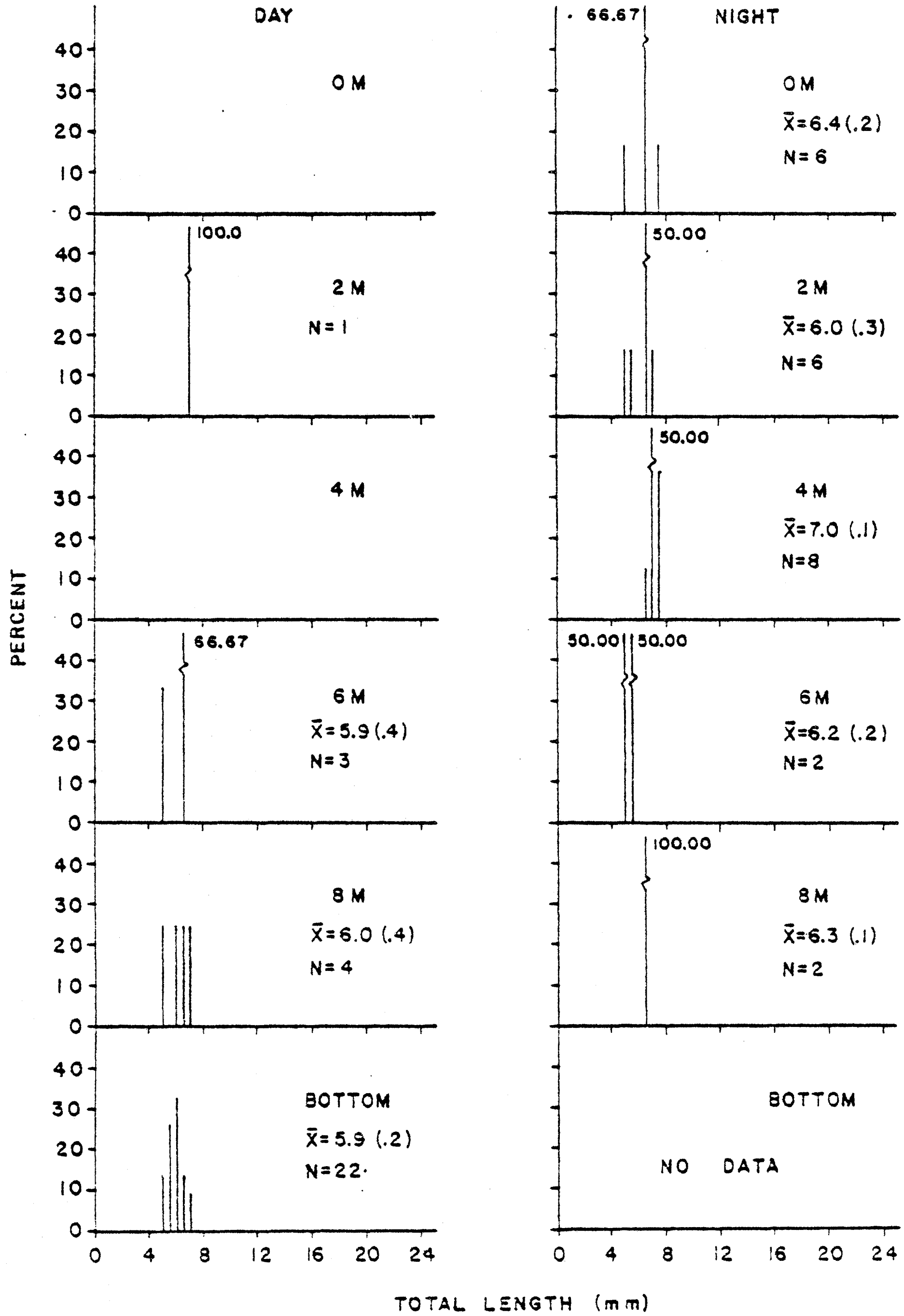

FIG. C18. A typical length-frequency histogram for rainbow smelt larvae captured during 13-14 May 1974 at the various depth strata of station D (9 m - Cook), southeastern Lake Michigan. Data are the percent of the total number of larvae captured, N = number of larvae captured, $\bar{X}$ = mean length and standard error is given in parenthesis. Bottom refers to sled tow data.

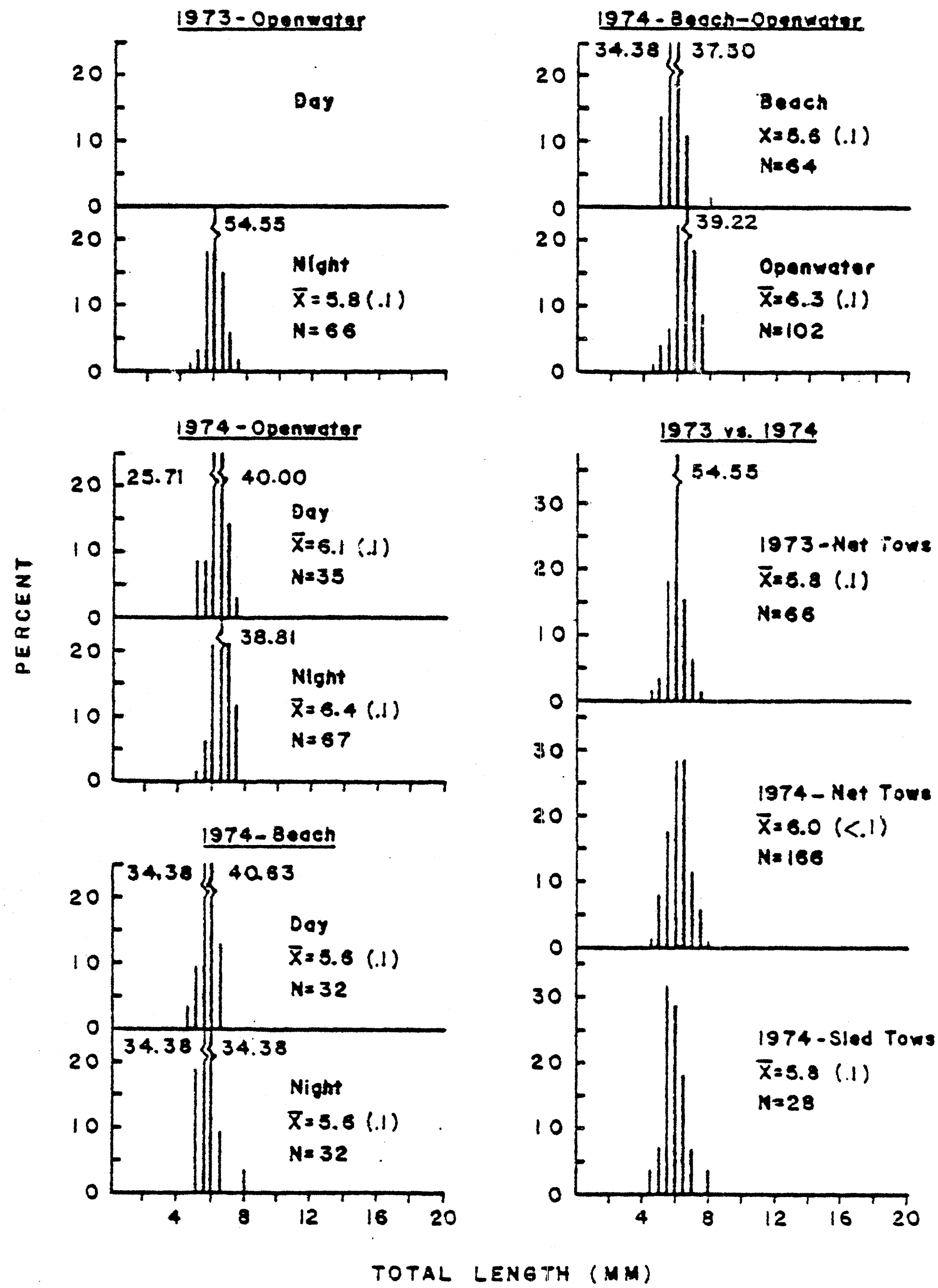

FIG. C19. Length-frequency histograms for rainbow smelt larvae caught in net and sled tows during April 1973 and May 1974 from Cook Plant study areas, southeastern Lake Michigan. Data were selectively pooled over day and night, station and depth as indicated. N = number of larvae used in the comparison, $\overline{X}$ = mean length of larvae. Standard error is given in parenthesis. Sled tow data include only stations P - 1.5 m through D - 9 m as no beach tows were performed in May.

attain a larger size by mid-June and July, entrainment potential should be reduced. However this size group (15-30 mm) was difficult to sample. Smelt this size were not very susceptible to our entrainment sampling pump in the forebay, nor were they impinged, as they probably passed through the 9.5-mm (3/8 in) mesh of the traveling screens.

Yellow Perch --

Introduction -- Yellow perch are a widely distributed fish, highly favored for their excellent tablefare qualities. Yellow perch populations in Lake Michigan have been characterized by considerable fluctuations according to commercial catch statistics (Wells and McLain 1973). The alewife has been implicated either directly or indirectly in causing recent declines in yellow perch numbers (Smith 1968a, 1970). Importance of yellow perch to sport and commercial fishermen has led us to pay considerable attention to the early life history of this species. We are also interested in interactions of yellow perch with other species at this life stage, particularly the mechanism by which alewife may affect their numbers. Understanding the distribution and behavior of the larval stage of this important fish can also assist in evaluating the effect of the D. C. Cook Plant on yellow perch larvae and provide information for use in future siting of water intakes in Lake Michigan.

Seasonal occurrence -- Yellow perch larvae were first noted in 1973 samples on 28 April in a surface tow at station G (6 m - Warren Dunes) and on 17 May in a surface tow at beach station A (N Cook). Lengths of larvae were respectively, 6.9, 6.9 and 7.3 mm. Water temperatures were respectively 7.5 and 10.7 C for the April and May catches. No perch larvae were caught this early during 1974. Since yellow perch spawn much later in Lake Michigan (late May - early June according to our adult gonad data), these larvae must have entered Lake Michigan from adjacent water bodies. Yellow perch larvae were also noted earlier than expected (early May) both in 1972 and 1973 by Wells (1973, 1974) in southeastern Lake Michigan waters. In our study area, the first major occurrences of yellow perch larvae, believed to originate from Lake Michigan-spawned perch, were on 18-19 June 1973 and on 11-12 June 1974. Water temperatures from which perch larvae were captured in 1973 were 20-21 C, while in 1974 they were 14-18 C.

Perch from June 1973 catches ranged in length from 6.2 to 7.4 mm, while 1974 collections contained perch from 4.9 to 7.5 mm (Fig. C20). Most larvae from both years were newly-hatched individuals since Norden (1961) and Dorr et al. (1976) have found perch hatch at about 5-6 mm.

Mansueti (1964) found perch to hatch after a 25-27 day incubation period at 8.5-12 C which was greater than Hokanson and Kleiner (1974), who found perch hatched after 6 days at 16 - 20 C and 20 days at 5 C. Hokanson and Kleiner (1974) also found that the optimum thermal regime for culture of perch was an initial exposure of fertilized eggs to 10 C and then exposure to 20 C before hatching. Clady (1976) found yellow perch in Oneida Lake hatched over a 2-wk period. Maximum size of newly hatched larvae was 6.2 mm and larvae grew 0.1 mm/day. A recent (June 1977) sample of yellow perch

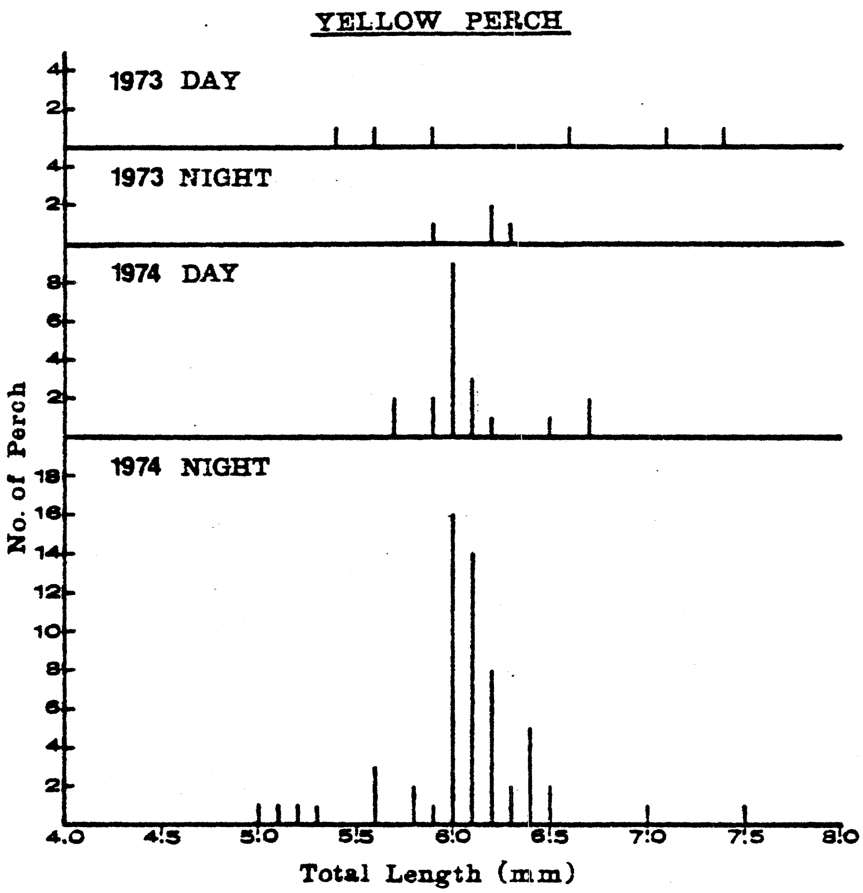

FIG. C20. Length-frequency histogram for all larval yellow perch caught in plankton nets and sled tows during June 1973-74 in Cook Plant study areas, southeastern Lake Michigan.

eggs from Lake Michigan near Cook was collected by our SCUBA divers. Eggs were hatched and 35 larvae about 2-3-h old were measured; they ranged in size from 5.5 to 5.8 mm.

Yellow perch eggs have only been collected 2 of the 5 yr of regular SCUBA observations at the Cook Plant. One strand of eggs was observed during 25 June 1975 in the riprap of the intake (9 m). Water temperature on the bottom was 17.8 C.

Perch eggs were also collected during 1977. On 19 May one clump of several thousand eggs was collected by divers from the riprap of the north intake; water temperature was 15.7 C. Some of these eggs were hatched and the larvae reared. Four to five yellow perch egg masses were also observed by divers on 19 May 1977 in a suspected spawning area (rocky moraine) about 6.4 km north of the Cook Plant. Water temperature on the bottom at this site was 15-16 C.

This area north of Cook was examined again on 25 May 1977 for presence of perch eggs. Six 100-m^2 transects were swum and an average of 5.75 strands of yellow perch eggs/100 m^2 were found. Water temperature at this time was 16 C on the bottom. At the Cook plant intakes, also on 25 May 1977, nine transects of 100 m^2 were swum and an average concentration of 0.58 strands of yellow perch eggs/100 m^2 were found. Clearly the area north of Cook was a more attractive spawning site to yellow perch than the Cook plant intake riprap.

Brazo (1973) found yellow perch spawned in late May at Ludington which is north of Cook on Lake Michigan. Larval sampling by Wells (1973, 1974) established 25 June-5 July as first occurrence of yellow perch larvae near the Cook Plant in 1973 and 18-20 June during 1972. Related work on larval yellow perch in a Wisconsin inland lake (Faber 1967) showed perch first appeared there consistently in late May when water temperature ranged between 13 and 18 C. Perch in Lake Oneida (Clady and Hutchinson 1975) spawned at 7-11 C. Results of studies of Lake Erie larval populations (Hemmick et al. 1975) showed that peak abundances of yellow perch occurred sometime before 2 June in 1975.

Yellow perch larvae rapidly attained a size (usually greater than about 8 mm) when they easily avoided a plankton net resulting in few larvae captured after their peak hatching period. No perch larvae were taken after June in 1973 at Cook and only two were taken on 9 July 1974, probably the result of a late hatch, since their lengths were 5.9 and 6.0 mm. The longest perch larva captured during 1973-1974 was 7.5 mm, with only 4 of 98 captured greater than 7 mm. Wells (1973, 1974) in his 1972-1973 studies along the southeastern shore of Lake Michigan, which included the Cook Plant area, found a similar short-term occurrence of perch larvae in his samples. They were found during 18-20 June to 20-23 July 1972 and 27 June to 31 July 1973. We also found higher night than day catches of perch, a phenomenon which was attributed to net avoidance. Nelson et al. (1967) warned about bias introduced by gear selectivity in that only the younger or slower-growing individuals were captured. This can give erroneous growth rate estimates or confound statements on distribution, unless different gear are used to collect fish. For a further discussion of the growth and distributional changes of YOY yellow perch see SECTION B -- Yellow Perch.

It is our feeling that significant spawning by yellow perch did not occur in the immediate vicinity of the Cook Plant, but in some other area in Lake Michigan. Our SCUBA divers have found large concentrations of perch egg masses about 2 km north of the Cook Plant in a rocky moraine (discussed earlier). Some rocky substrate areas near Saugatuck are also thought to be perch spawning grounds (L. Wells, personal communication, Great Lakes Fishery Laboratory, U.S. Fish and Wildlife Service, Ann Arbor, Mich.). We have found a few instances where an occasional strand of yellow perch eggs was found by SCUBA divers on the Cook Plant riprap (25 June 1975 - 9 m) and parts of strands in entrainment samples. Ripe adult yellow perch were never found in large numbers around the plant during suspected spawning times

(late May-early June), but spent individuals appeared in sometimes large numbers in mid and late June.

Houde and Forney (1970), Noble (1970) and Houde (1969) have found that yellow perch in Oneida Lake after hatching were distributed in the lake in a specific manner dictated by prevailing winds and currents. High winds killed yellow perch eggs in Oneida Lake through dispersal and physical destruction (Clady and Hutchingson 1975). They found interactions between low water temperature, high wind and possibly other factors, resulted in the death of large numbers of yellow perch before cohorts became pelagic. Early survival for Oneida Lake perch (from egg to 8 mm) varied from 1.6 to 18.4%. Two variables, air temperature 3 wk before larvae attained 8 mm and wind velocity 4 wk prior to this date, accounted for 87% of the variability in survival of yellow perch larvae. Many studies cited in Eipper (1975) also stress the strong correlations consistently found between water temperature during the first few weeks following spawning and year class strength. Both Clady and Hutchinson (1975) and Eipper (1975) concluded that both air temperature and wind are probably responsible for year class strength through a combination of these factors and secondary induced effects, such as starvation, predation, structural abnormalities and behavior modification. Another factor which is critical to larval survival is food availability. Recent marine work (Laurence 1974, Lasker 1975, May 1974) has documented the importance of the correct particle size and concentrations of food necessary for survival of first-feeding larvae. Lasker found that the density of food usually found at sea was far to low to obtain even moderate larval growth and survival. He found during one on-ship experiment that feeding by larval anchovies in surface waters was minimal, but extensive feeding occurred in water from the chlorophyll maximum layers when these contained phytoplankters having minimum diameters of approximately 40 microns and which occurred in densities of 20 to 40 particles/ml.

It is not unlikely to suspect a similar sequence of events in southeastern Lake Michigan. Thus abundance of yellow perch larvae at the Cook Plant is dependent on proximity to spawning sites, magnitude of the spawn, amount of egg production, larval mortality and the caprice of wind-generated currents. Houde (1969) found from his lab studies that yellow perch under 9.5 mm TL could not sustain themselves in current velocities of 3.0 cm/s. Therefore he concluded that newly-hatched larvae would be subject to transport by currents of greater velocity. Currents in the Cook Plant vicinity regularly exceed that velocity. Random patchy distributions of newly-hatched yellow perch larvae should result from this mode of dispersal until they reach a size where they could have more control over their movements or become demersal in habit, which occurs at about 30 mm according to Wong (1972) and 25 mm according to Forney (1971). From his Lake Michigan data, Wells (1973, 1974) concluded that yellow perch indeed use the entire shoreline from New Buffalo to Frankfort as a nursery ground. Greatest production in 1972 (determined from catches of YOY perch) was in the Benton Harbor area. Ward and Robinson (1974) found yellow perch in West Blue Lake, Manitoba (31 m maximum depth - 160 hectares) moved offshore soon after hatching in late spring-early summer and occupied the epilimnion

throughout mid-lake. In early August at about 30 mm, mid-lake catches of perch declined and increasing numbers were caught by seines in the littoral zone--we have also taken large numbers of perch, although somewhat longer ($\bar{x}$ = 43 mm ± 4 SD) in seine hauls during August 1973 at Cook Plant beach stations. A similar phenomenon can be inferred from Faber (1967), who in his studies of two Wisconsin lakes found that as the season progressed, yellow perch were in the limnetic zone in increasing numbers up to a maximum, then occurred in decreasing numbers, presumably when they moved to the littoral zone. He attributed his failure to capture perch to net avoidance. Perch are known to school from the middle of the larval period onward (Disler and Smirnov 1977, Schumann 1963).

Diel distribution -- Considering the 98 perch larvae captured during June-July 1973-1974 (Fig. C20) almost twice as many were caught during the night (65) as during the day (33). As discussed earlier, most of this difference is believed due to net avoidance. At most stations, night catches at a particular depth exceeded comparable day catches. For example, night surface tows during 11-12 June 1974 (Fig. C21) at stations C (6 m) and D (9 m) contained 940 and 610 perch larvae per 1000 m^3 respectively; no larvae were caught during comparable day tows. Results for 1973 (Fig. C22) were similar, although at the 1- and 2-m depths at the 9-m Cook station more larvae were captured during the day than at night.

The only larvae caught in July were also taken during night tows. This phenomenon of net avoidance by yellow perch and other species, as exhibited in day-night differences, has been discussed and confirmed by many workers (Ward and Robinson 1974, Faber 1967, Isaacs 1964, Wells 1974). Bridger (1956) found North Sea herring larvae were caught from four to six times more often at night than during the day. Wong (1972) using a meter net in West Blue Lake, Manitoba found maximum catch of yellow perch in a 24-h diel study he conducted occurred in surface waters at 2400. Wong also found another increase in catch a short time after sunset, but not during the period of lowest light intensity (0100-0400 h). Ali (1959) found for sockeye salmon that a partial night blindness developed if the rate of dark adaptation by the eyes was slower than the rate of decrease in light intensity. Thus, Wong (1972) has proposed that a combination of partial night blindness and low efficiency of scotopic vision was responsible for the ease of capture of perch at night and after sunset. Wong found no increased catch at dawn when perch changed from scotopic vision to photic vision. Another point, which may explain larval perch diel activity, was that these larvae were suspected of feeding continuously, with peak gut fullness found at 2100 (Wong 1972).

Vertical distribution -- Yellow perch larvae at open water 6- and 9-m stations were generally found most often in surface and near surface tows (Figs. C21 and C22). However, some were caught at all intermediate depths. Yellow perch were only caught once in bottom sled tows on 11 June 1974 at beach station A (1 m - N Cook), despite extensive effort with the sled at beach and open water stations out to 9 m, further confirming their early existence in surface offshore waters and their pelagic distribution.

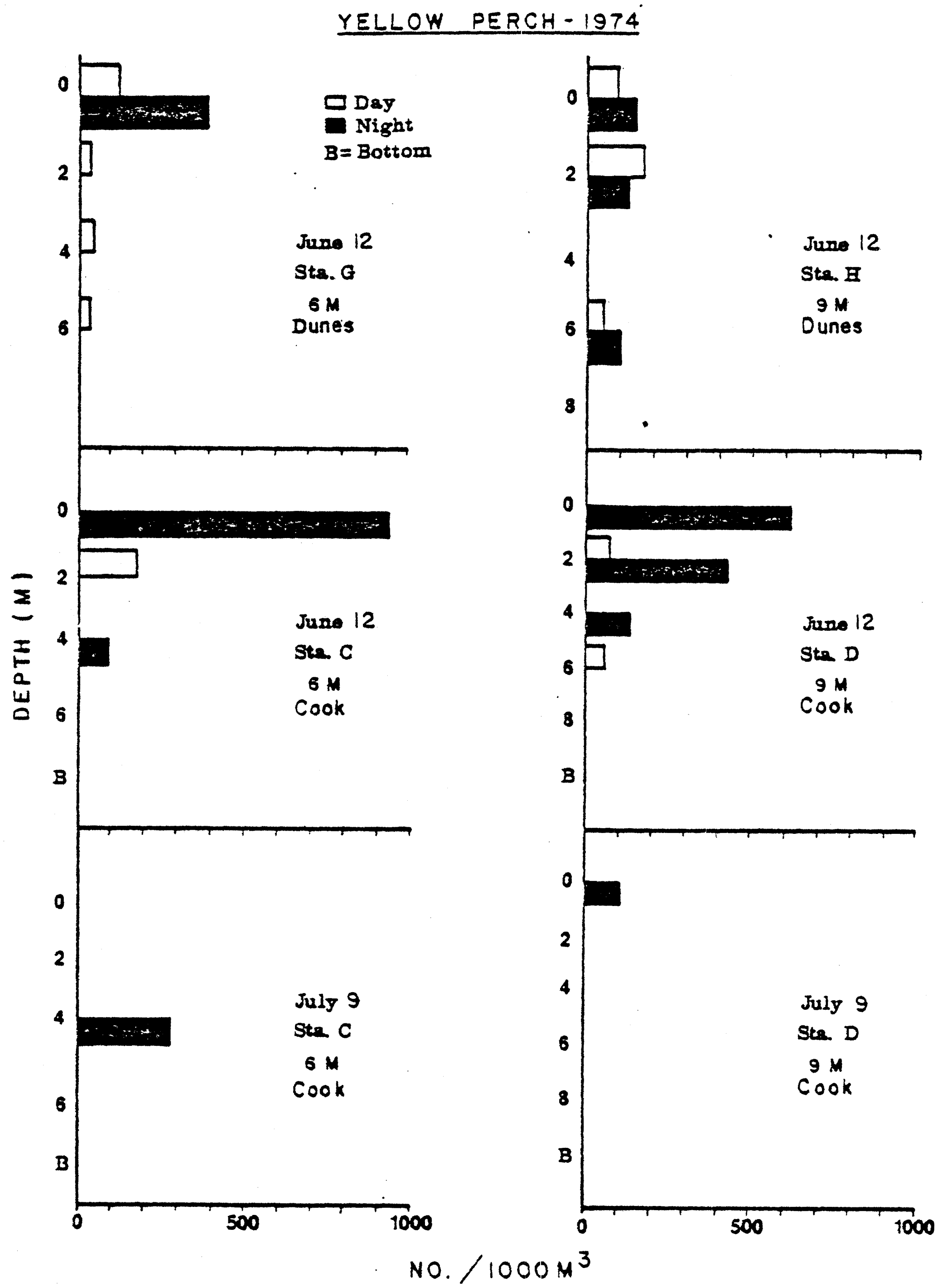

FIG. C21. Vertical distribution in no./1000 m^3 of yellow perch larvae captured during day and night sampling June-July 1974, at Cook Plant and Warren Dunes 6- and 9-m stations, southeastern Lake Michigan.

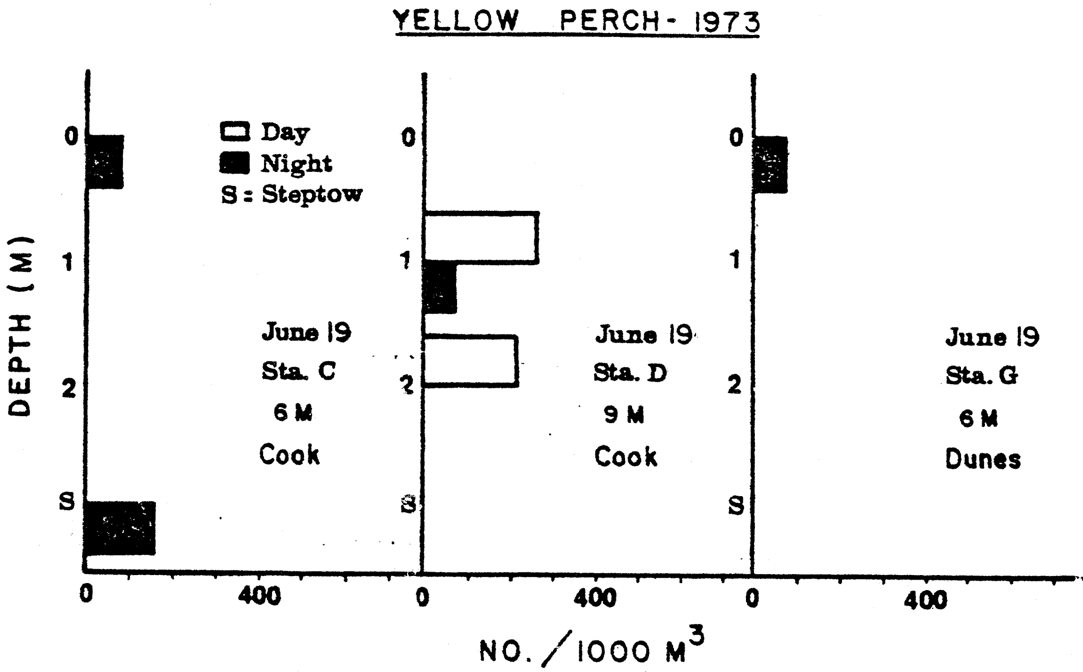

FIG. C22. Vertical distribution in no./1000 m^3 of yellow perch larvae captured during day and night sampling June-July, 1973 at Cook Plant and Warren Dunes 6-and 9-m stations, southeastern Lake Michigan.

Occurrence of perch in the beach zone sled tow sample was attributed to wind-induced currents which deposited part of a yellow perch egg mass inshore. We subsequently examined these larvae, which were newly hatched since they were unusually small and many still had yolk sacs. Wells (1973) also found yellow perch larvae in Lake Michigan during the day were usually at 1-3 m beneath the surface with some also found at all depths sampled. Clady and Hutchinson (1975) found Oneida Lake yellow perch larvae behaved similarly--few were ever collected below 5.5 m. Wong (1972) also found perch larvae occupied the top 5-6 m of water during July in West Blue Lake, Manitoba. Noble (1968) found that perch were usually in surface waters in Oneida Lake, but sustained winds caused perch to shift to deeper water. In Lake Erie, because of winds and strong currents, perch either occupied protected inshore areas or moved deeper (Turner 1920).

No yellow perch were actually caught at our 1-m beach station during June 1973 despite information to the contrary in Table C1, Jude et al. (1975). (Yellow perch indicated as being present at beach stations A and B were later identified as spottail shiners, but the correction failed to be added to final text.) In 1974 on 11-12 June, yellow perch were found in surface tows at beach station A (N Cook) in numbers up to 391/1000 m^3 and station F (Dunes) in even larger numbers, 598/1000 m^3 (Fig. C23). Surface tows on 25 June 1974 also contained perch at beach station A, although in somewhat lower numbers--65/1000 m^3.

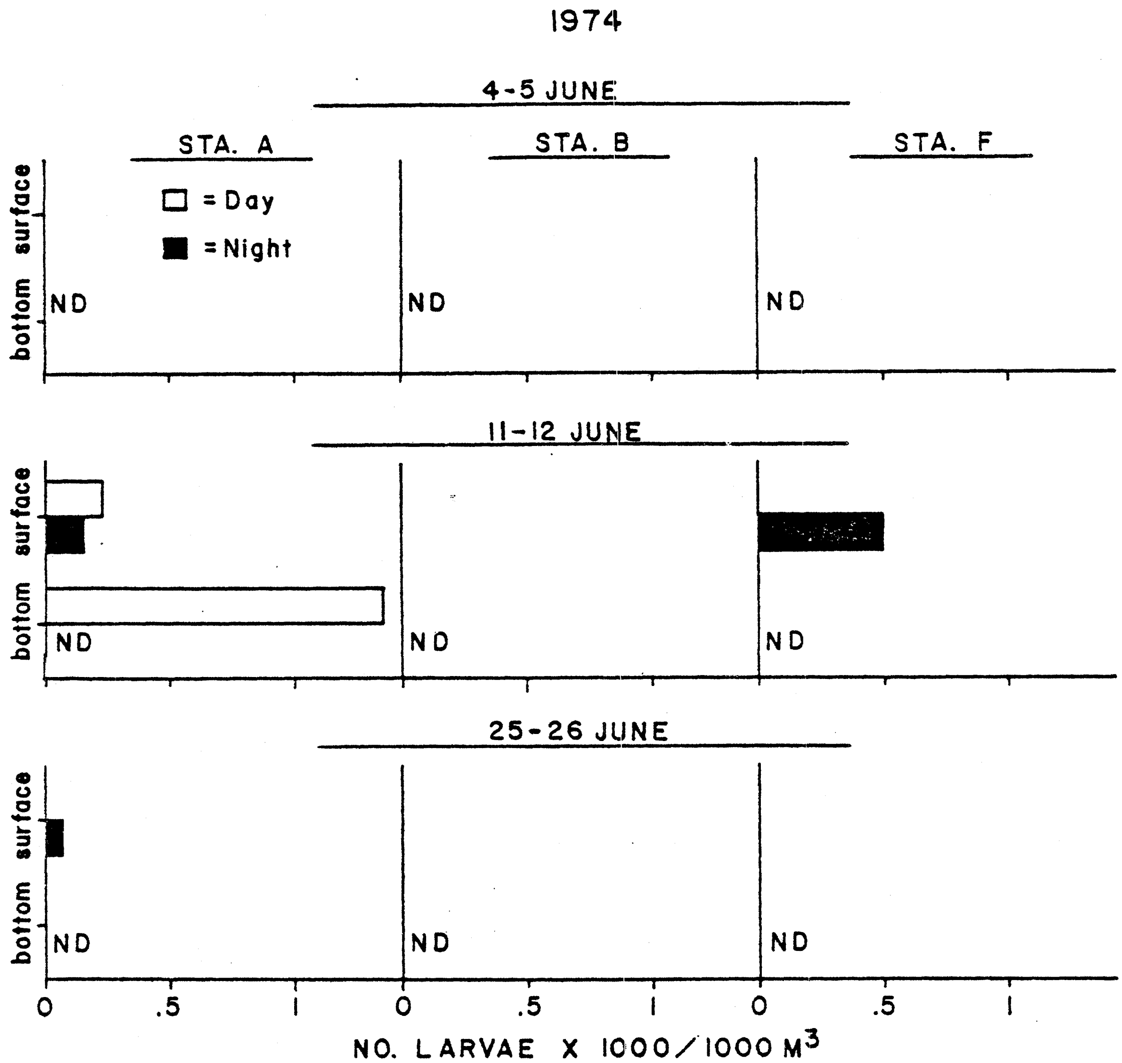

FIG. C23. Vertical distribution of yellow perch in no./1000 m^3 during day and night sampling, June 1974 at Cook Plant beach stations. Surface samples were collected in duplicate and the mean shown; only one tow was made with the sled for bottom data.

We saw no indication of a diel vertical migration for perch as was suggested for West Blue Lake, Manitoba (Ward and Robinson 1974, Wong 1972). They found that perch larvae tended to be near the bottom during day and at the surface in large numbers during the night. Light was thought to be the main governing factor in this migration.

In our study yellow perch were apparently more abundant during 1974 (88 caught) than 1973 (10 caught), since considerably more perch were taken. However, because our sampling was usually done only once per month, peaks could easily be missed. Wells (1973, 1974) noted that catches of perch fry at east-shore stations were much smaller in 1973 than in 1972, leading him

to the tentative conclusion that 1973 was a poor year for perch reproduction. However, he cautioned that scarcity of perch in 1973 samples may be due to timing of the sampling. He further stated that most larvae appeared to hatch over a brief period and lose their vulnerability to the 0.5-m diameter nets at an early age because of avoidance or residence on the bottom. We concluded from our sled tow sampling that perch larvae less than 7.5 mm were not residing on the bottom, at least not in sandy areas. Averaging the concentration of perch larvae from our top two tows (1974) or three tows (1973) at the four open water stations (C, D, G, H) for June gave a mean concentration of 29/1000 m^3 for 1973 and 182/1000 m^3 for 1974. Yellow perch larvae were over six times more abundant in the Cook Plant vicinity in 1974 as in 1973. Consulting yellow perch YOY standard series catches (SECTION B, Yellow Perch) showed that contrary to these results, 1973 was a better year for abundance and growth of YOY perch than was 1972 or 1974. It was thus our feeling that the 1973 peak of larval yellow perch abundance was undoubtedly missed, as this period was brief and monthly sampling was simply inadequate to document peak abundance of larval perch. In addition, since perch were not spawning in the immediate area, we were not sampling where they attained maximum densities, and thus may never sample adequately to establish a peak. Thus, predictions of year class strength from monthly larval perch data should not be attempted; at least weekly sampling during late May-early July would be necessary to define these relationships.

In 1972 Wells (1973) found concentrations of yellow perch larvae at the 5.5- and 7.4-m stations around the Cook Plant to range from 0-71/1000 m^3 with sampling dates on 27-28 May, 18-20 June and 28 June-4 July 1972. In 1973 Wells (1974) found only one occurrence of perch (9/1000 m^3 on 27 June-5 July) at his 5.5- and 9.2-m stations around Cook, despite sampling on 17-24 May, 27 June-5 July and 18-31 July. Our sampling at Cook on 18-19 June 1973 corresponded with that of Wells (1974) who found no perch larvae around Cook then. We found concentrations of larval yellow perch, mostly at night (three stations--C, D, G) which ranged up to 250/1000 m^3. As noted, average concentration of the top three tows (0, 1, 2 m) at open water stations during June 1973 was 29 larvae/1000 m^3. Our sampling on 11-12 June 1974 showed perch were quite abundant at our 6- and 9-m stations around Cook Plant study areas, ranging up to 938 larvae/1000 m^3 in a night surface tow at the 6-m Cook station. As noted previously, the average concentration in the top two tows for all open water stations was 182 larvae/1000 m^3. It thus appears that, as discussed, the peak period of vulnerability of perch to plankton nets was short and that Wells undoubtedly missed it during his 1972-1973 sampling and that we probably did likewise during 1973. Our 1974 sampling apparently more closely reflected abundance during the peak period of larval abundance.

Horizontal distribution -- Yellow perch larvae were found in the inshore waters of Lake Michigan with a few occurring in the beach zone and higher concentrations at 6- and 9-m depths. We never caught any yellow perch at our 21-m station during day sampling 19 June, 16 July 1973 and 12 June, 9 July 1974. More sampling at intermediate depths (10-21 m) and night

sampling at 21 m would help confirm the apparent lack of perch in the deeper waters of Lake Michigan. As noted before, Ward and Robinson (1974) found that yellow perch in a large Manitoba lake moved to the epilimnion in mid-lake after hatching in the littoral zone. Faber (1967) also found larval perch in the middle of the small Wisconsin lakes he studied and Noble (1968) reported perch became pelagic at 9 mm. Schumann (1963), during experiments rearing walleye and yellow perch larvae in Wisconsin, found that a markedly positive phototaxis developed in larvae soon after hatching. Yellow perch were strongly attracted to an artificial light throughout larval development and well into the fry stage. The degree to which young perch were attracted to the light seemed to be correlated with the size of the fish. As perch grew, fewer were attracted to the light and they tended to remain deeper in the water. Larvae were not found in shallow water near shore until late at night, indicating that larvae spread out in surface waters over shallow and deep areas of lakes. By 20 July 1961 perch fry in these Wisconsin lakes began moving into the littoral zone. In contrast, Wong (1972) for West Blue Lake, Manitoba, found that postlarval perch (over 10 mm) were readily collected from the lake surface and that they moved to the shallows by 8 August. At this time they were about 30 mm and possessed the characteristic dark vertical bars. From 1 July through 31 August, perch grew 0.5 mm/day.

Length-frequency histograms -- The pattern of not catching any yellow perch larvae after they reached about 8 mm was amply demonstrated by the June 1973-1974 length-frequency data (Fig. C20). Most larvae captured were around 6 mm. Precedence for a species-specific length, or breakpoint in larval development was given by Sette (1943) for mackerel in the Atlantic Ocean. He found that mackerel larvae had two phases--an early passive phase lasting through 8-10 mm and thereafter an active phase where larvae exercised more control over their distribution. In the passive phase, mackerel larvae (probably like yellow perch) were semi-planktonic and subject to transport by strong currents. Yellow perch when they enter the active phase also exhibited striking net avoidance.

More perch larvae were always caught at night when contrasted with the comparable day data. No tendency, as was expected, to catch somewhat larger larvae at night was observed. Apparently a wide length range of perch was not available because of the contracted hatching period. Capture of more perch at night was thus attributed to inability of perch to escape a net as well at night as they can during the day--alluding to visual cues as important components of this avoidance reaction. As perch grow older, perhaps currents and shock waves generated by the net apparatus are more important.

Potential entrainment impact -- Entrainment of larvae in large part depends on their distributional vulnerability in relation to the intakes and current present in the 4- to 6-m depth strata at the 9-m contour, ability to detect a current, behavior (whether avoidance or attractive, once in the path of the intake) and changes in these factors as modified by storms and subsequent currents and high seas generated. Yellow perch appeared to have

a low entrainment potential, based mainly on their upper water (top 1-4 m) distribution and relatively low abundance in the study area. Because some perch larvae have been found throughout the water column, some entrainment of larvae is expected to occur although none has been observed during 1974 (SECTION D). Examination of entrainment data from 1975-1977 showed yellow perch regularly entrained in modest numbers, usually during June. Because of their ability to avoid nets at an early age, they should easily be able to avoid the (0.37 m/s) intake velocity. Whether they do or not is unknown. Houde (1969) gives a good predictive clue as to how one might expect a newly-hatched yellow perch larva to behave at an intake pipe. In his swimming speed tests with 6.5-mm larvae, he found they did not respond to currents (2-7 cm/s), but allowed themselves to be rolled along the length of the tube. Larvae of increasing length (up to 14 mm) oriented to current and became successively stronger at resisting given currents for long periods of time.

Less Abundant Species

Trout-perch --

Distribution and abundance of larval trout-perch in Cook Plant study areas still remains a perplexing question. No trout-perch larvae were collected in plankton nets during 1973 (some larger fry were trawled) and only five were captured during 1974 (Table C4)--two were found in sled tows, two were entrained and one was taken in a surface tow in the beach zone. Since adults were reasonably common in our collections (fifth most numerous fish), we expected to collect more of their larvae, particularly in the benthic sled tows initiated in 1974.

Some support for an extended spawning period for trout-perch exists in the literature. Scott and Crossman (1973) observed that lake-spawning populations of trout-perch seemed unique in that spawning was prolonged, May-August in Lake Erie. Magnuson and Smith (1963) in the Red Lakes, Minnesota considered spawning to occur from 5 June to 23 August 1956-1957. Regarding other water bodies, trout-perch have been recorded as spawning in streams or shoals of large lakes (Scott and Crossman 1973). There are two small streams and the St. Joseph River near the study area where trout-perch may be spawning, but it is our feeling that perhaps some rocky areas or other special bottom types may be attracting and concentrating trout-perch in areas away from the Cook Plant. Spawning may be so scattered in time and space that larvae may always remain scarce. Subsequent years' sampling and SCUBA observations may help answer this question.

First occurrence of trout-perch larvae was on 25 June 1974 when a 6.0-mm specimen was caught in a night surface tow at beach station A (N Cook). Water temperature was 13.1 C. We suspect this larva was a newly-hatched specimen. Dorr et al. (1976) and Fish (1932) listed 5.5 mm as hatching length and specimens hatched on 28 July 1976 by H. Blankespoor (Hope College, Holland, Michigan) by mixing eggs and sperm from adults collected from Douglas Lake, Pellston, Michigan were 5.3 and 5.8 mm and 5.8 and 6.0 mm, 1 and 2 days respectively after hatching. Eggs hatched in about

6 days. Langlois (1954) stated that trout-perch eggs hatch within 20 days. Thus, an early June spawning season was inferred from our specimen caught on 25 June, and an even earlier season could be inferred from the collecting of ripe-running adults in May trawls (see SECTION B - Trout-perch).

Benthic sled tows accounted for the capture of trout-perch larvae at night, one on 20 August at 9-m station D and the other at 1.5-m station P on 11 September 1974 (Table C4). Length of the trout-perch caught in August was 8.0 mm; the September-caught fish was only 6.1 mm implying spawning had occurred in late August-early September. Further evidence of an extended spawning period was provided by the 6 August 1974 entrainment samples which contained a 6.1-mm trout-perch. A larger trout-perch larva (18.0 mm) was found in a 20 November entrainment sample. Young-of-the-year trout-perch in 1973 first occurred in September trawls at a modal length of 25 mm.

During trawling on 26-27 October 1973 at stations C (6 m - Cook) and H (9 m - Dunes), a large number of trout-perch from 12-18 mm and 25-40 mm were captured. Young-of-the-year were never caught by seining, apparently ruling out this habitat as a nursery ground for larger larvae (>12 mm). Wells (1973, 1974) in his 1972 and 1973 larval fish sampling of the eastern and part of the western shoreline of Lake Michigan found only one occurrence of trout-perch -- a 1-m tow (9-m station) on 25-30 August 1972 at Grand Haven, Michigan. It is clear from these 1974 occurrence data that larval trout-perch are not very abundant in the study area, are mostly demersal in their distribution, occur in the beach zone and out to at least 9 m and apparently are hatching from June through September. Since all larvae, except the 18.0-mm entrained specimen, were captured at night, it appears these larvae, much like yellow perch, are adept at avoiding our ichthyoplankton gear.

It is obvious from our entrainment data that some trout-perch are being entrained, despite the feeling that vulnerability to the intakes should be low because few larvae appear to be present in the area. Some spawning may occur in association with the intake and discharge riprap, leading to increased entrainment because of proximity to the intakes.

Carp --

One of the observed effects of power plant intake and discharge systems has been the attraction of fishes to the thermal plume generated from discharge of heated water. The ubiquitous carp has been the species most commonly implicated or observed at such heated water outfalls (Jude et al. 1975; Benda and Gulvas 1976). A similar pattern has also been documented at the Cook Plant. Our preoperational sampling for adult fish (SECTION B - Carp) and preliminary operational data showed an increase in the number of adult carp at both Cook and reference stations each year. There was a larger buildup of carp at the Cook Plant, however, than at Warren Dunes stations within a given year. During 1973-1974 no carp larvae were collected, implying no substantial spawning by this species occurred in preoperational years. In 1975-1976 (unpublished data) however, carp larvae were captured.

Table C4. Date, station, depth, water temperature and concentration of miscellaneous species of fish larvae captured in Cook Plant study areas during 1973-1974. (B = bottom).

Species	Date	Diel Period	Gear	Station	Depth (m)	Water Temperature (C)	Length (mm)	Concentration (No./1000 m^3)
Trout-perch	25 Jun, 1974	Night	Net	A	0.5	13.1	6.0	64
	20 Aug, 1974	Night	Sled	D	B-9	17.0	8.0	46
	11 Sep, 1974	Night	Sled	P	B-1.5	20.0	6.1	42
	6 Aug, 1974	Night	Pump	S-intake	1	20.5	6.1	329
	20 Nov, 1974	Day	Pump	S-intake	5	5.0	18.0	24
Ninespine stickleback	25 Jun, 1974	Night	Net	A	0.5	13.1	9.0	65
Johnny darter	10 Jul, 1974	Night	Sled	D	B-9	14.5	10.0, 10.0	123
Slimy sculpin	12 Jun, 1974	Night	Sled	D	B-9	14.5	12.0	49
	26 Jun, 1974	Night	Sled	N	B-3	13.0	9.1	46
	10 Jul, 1974	Night	Sled	D	B-9	14.5	15.0	61
	16 Jul, 1974	Night	Sled	D	B-9	11.7	11.0	49
Unidentified species	12 Jun, 1974	Night	Net	A	0.5	18.2	3.6	139
	25 Jun, 1974	Night	Net	B	0.5	13.1	4.3, 5.0, 6.0, 7.0	176
	11 Jun, 1974	Day	Net	F	0.5	17.5	3.0	133
	8 Jul, 1974	Day	Sled	A	B-1	22.5	6.0	338
	6 Aug, 1974	Night	Pump	S-intake	5	20.5	4.9	287

Significance of reproduction by this fish must be tempered by our belief that few, if any, of these larvae ever survive to become adults. Evidence for this view comes from the paucity of YOY carp in any of our catches (except one 125-mm specimen seined in April 1974) during at least 5 yr of fishing in the area with trawls, seines and gill nets. We believe the Lake Michigan environment is too harsh for larval carp, whose normal nursery areas are backwaters and shallows of lakes and rivers. Our future sampling should help clarify this assumption.

We expect that adult carp will continue to be attracted to the plume area in increasing numbers with increased spawning also taking place. Subsequently, more carp larvae will probably continue to be observed in the area of the plume. Limited available data on entrainment during 1976 showed that carp larvae were entrained on 15 June, 15 July and 4 August, further proof of spawning activity around areas of the Cook Plant riprap and heated discharge.

Burbot --

Adult burbot is a rarely caught species in Cook Plant inshore waters, but unlike many of our other rare species which do not spawn here, burbot do come into inshore waters during winter months to spawn. We observed ripe-running females in gill nets during December 1973 and found burbot eggs in our beach fish larvae samples in January 1974 at station A (N Cook). Scott and Crossman (1973) noted that burbot spawned from January to March in Canada. In 1974 we believed that larvae should be taken in future larvae samples. In 1973-1974 we did not catch any burbot larvae, which was also true of Wells (1973, 1974) in 1972-1973. In 1975 during April and May open water tows at stations C (6 m), E (21 m off Cook) and W (21 m off Warren Dunes), three burbot larvae ranging in size from 4.0-4.5 mm were captured. More burbot were captured in 1976 and 1978 but only 1975 larvae will be discussed here. Muth (1973) and Muth and Smith (1974) listed 3.87-4.19 mm as hatching size for burbot raised from Lake Superior, suggesting our larvae were newly hatched. The larva taken at station C (6 m - S Cook) was collected on 14 April 1975 from the 4-m day tow when water temperature was only 2.2 C. The next one came from the 21-m Cook station on 16 April 1975 and was caught in the 13.5-m day tow. Water temperature was 3.5 C. The last larva was collected during the day on 13 May 1975 at the 21-m Dunes station in the 13.5-m tow when water temperature was 5.0 C.

Scott and Crossman (1973) stated that burbot eggs hatched in 30 days at 6.1 C and the young appear from late February to June. Chen 1969 found that burbot in the Tanana River, Alaska spawned in early February and eggs hatched in late April. Burbot larvae grew rapidly and attained a length of 110 mm in their first year of life. Bailey (1972) found that burbot from Lake Superior attained 145 mm in their first year of life. The incubation period for burbot eggs in Chen's study was from 1.5-2.5 mo. Eggs were hatched in 30 days at a constant temperature of 6.1 C, and 41 days at 2 C. Newly hatched fry averaged 4.06 mm, similar to that found by Muth. Fish (1930), for Lake Erie burbot, found that larvae, from eggs hatched in

mid-June, attained a length of 10-15 mm by August and 30 mm by late August. Bailey (1972) found that adult burbot collected nearshore in the Apostle Islands area in late January and February were spent; whereas, none collected in offshore areas during January and March had spawned.

It appears, from our limited data, that spawning has occurred at least in the inshore waters (1.5-3 m where gravid fish were caught in December) near the Cook Plant and that waters from 6 m to at least 20 m are nursery areas for burbot larvae. Since burbot do not build a nest and give no care to the young, it is probable that the entire shoreline is a spawning and nursery area for them. Some entrainment of burbot larvae is expected and perusal of 1976 entrainment data showed that one was entrained on 29 April. Because of the rarity of these larvae in Cook waters, impact on burbot populations is expected to be low.

Johnny Darters --

Johnny darters were the sixth most frequently captured adult fish in the Cook Plant area in 1973 and 1974, so spawning by these fish was expected in the study area, particularly among riprap. SCUBA divers (Dorr and Miller 1975) have observed johnny darters to be the second-most common fish next to sculpins, around the intake and discharge riprap. Johnny darters require the underside of rocks or trees to complete spawning so the riprap area should be ideal substrate. The spawning season for darters was estimated as occurring around late May-June from our adult gonad data and appearance of larvae. Johnny darter eggs hatched in 5-8 days at water temperatures of 22-24 C (Scott and Crossman 1973). Our SCUBA divers (unpublished data) collected darter eggs during 1977 on 25 May and 16 June. No eggs of johnny darters were observed by divers on 18-19 May or on 13 July, which suggests the period between 25 May and 16 June (21 days) as times of maximum spawning activity for johnny darter in this vicinity of Lake Michigan. During the 25 May 1977 dive, which was performed near the north intake structure (northeast side), darter eggs were found attached to the underside of a fiberglass tub. Depth of water there was about 8.5 m; water temperature was 18 C at the surface and 16.5 C on the bottom. Eggs were scraped from the tub, taken to the lab, where they hatched and were reared up to 7 days (larvae were not fed). The newly hatched larvae ranged from 3.8-5.0 mm (N = 22), 24-h-old larvae were 4.0-5.8 mm (N = 15) and at the end of 7 days lengths ranged from 4.0 - 5.8 mm (N = 12). On 16 June 1977 a dive was performed on the south discharge structure (depth about 6 m) and again johnny darter eggs were collected from the underside of riprap. These eggs were not reared. A dive on the intake structures (9 m) that same day revealed no darter eggs present there. The 1974 sled tows were responsible for the capture of two specimens, both 10.0 mm (see Table C4). These larvae were collected on 10 July at night from 9-m station D. In September 1973, a 19.0-mm larvae was trawled.

Though scanty, our data confirmed the belief that johnny darters are demersal and not very abundant in areas away from the riprap. Like sculpins, johnny darters are exploiting the riprap habitat created by the intake and discharge pipe laying. They may indeed be entrained in larger

numbers than suspected (none were observed in 1974 entrainment samples) because of their bottom-dwelling habits. More adult darters were caught during the night which was also true of larvae showing they avoid sled tows during the day. Darters appeared to be distributed in the 6- to 9-m depth zone, as no larvae and few adults were captured at beach zone stations. More data from stations deeper than 9 m would help clarify their distribution in the deeper waters of the Cook Plant study area.

Sculpins --

We have had difficulty in finding reliable characters to separate adult slimy from mottled sculpins, the two species of sculpins found in the study area. It is for this reason that we have designated these larvae as *Cottus* spp. Rottiers (1965) has stated that slimy sculpins were by far the predominant species in the area, however we have collected a number of adult mottled sculpins. Scott and Crossman (1973) and McAllister (1964) support the difficulty in separating these two species. McAllister demonstrated that none of the characters commonly listed in various keys would permit 100% separation of the two species. It is thus possible that some of the sculpin larvae collected could be mottled sculpin.

Only four sculpin larvae were collected with conventional plankton nets during 1973-1974 in the Cook Plant study areas (Table C4). These were all captured with the sled at night during 1974. Three were caught at the 9-m Cook station (D) on 12 June, 10 July and 16 July and one at station N (3 m) on 26 June. Lengths of these larvae were respectively 12.0, 14.5, 11.0 and 9.1 mm. Water temperatures at which they were collected ranged from 11.7 to 14.5 C. Adult sculpins are quite abundant around the intake and discharge riprap (SCUBA observations and Jude et al. 1975). On 21-22 May 1974 divers recovered egg masses estimated as having been laid by two female sculpins--water temperature was 11.1 C. Eggs subsequently hatched in the lab and the resulting larvae averaged 8 mm TL. From these observations and Rottiers (1965) an early May-mid May spawning season was inferred. Scott and Crossman (1973) cited a study of slimy sculpins in the Montreal River where spawning occurred at 8 C and hatching did not occur until 4 wk later. On 19 June 1973 a trawl haul at station E (21 m) produced a catch of sculpin eggs, eyed embryos and larvae--water temperature was 7.2 C. These fish were also suspected to be slimy sculpins. Rottiers (1965) suggested there may be two peaks in spawning by sculpins in Lake Michigan--one in spring by fish in shallow water and one later in the year in deeper water. Our adult gonad data suggested mid-April as spawning season for sculpins. Again both species may be involved resulting in an apparently prolonged spawning season.

Since some type of cover or rocks is usually required for spawning (eggs are laid underneath rocks, trees or similar structures--Scott and Crossman 1973), it follows that the Cook Plant riprap would attract this species during spawning season. Attraction and preference of sculpins for this riprap area has caused adult sculpins to be impinged at a high rate during certain periods of the year and undoubtedly many of their young are entrained. We have not caught any in entrainment samples during 1973-1974, but have in later years. Demersal behavior by sculpins probably kept them

from being sampled in the intake forebay, since the entrainment sampling hose was suspended 5 m in the 9-m deep forebay. However, they should be collected in the discharge forebay, since water entering there is well mixed.

We concluded from these data that sculpin larvae are demersal in habit, abundant around and within the intake and discharge riprap, but rare in the immediate and surrounding vicinity of the usual, featureless sandy area of Lake Michigan. Larvae are nocturnal like adults and most hatch during May to early June when temperatures range from 7 to 13 C. The potential for entrainment impact is high, since sculpin larvae hatch around the intake structure. Larvae would thus be exposed to the intake current at sometime during their movements or possibly attracted into the intake pipes because they are dark or induce a current. Since the plant was originally responsible for providing habitat upon which these fish now successfully spawn, impact assessment will depend on how many of the larvae survive and what importance the population of adult sculpins now living in the riprap is to the whole Lake Michigan population.

Ninespine Stickleback --

Adult ninespine sticklebacks were uncommon in the Cook Plant study area (19 caught in 1973, 25 in 1974) and none of their larvae were expected to be captured. However, a 9.0-mm specimen was caught in a surface-towed net on 25 June 1974 at the N Cook beach station (Table C4). Scott and Crossman (1973) cited a 2-wk-old ninespine as being about 15 mm and maximum length of YOY as being 38-46 mm. No evidence of spawning has been observed by SCUBA divers nor were any YOY sticklebacks captured by any of our gear. Thus, occurrence of this single larva may have been due to either an isolated spawning around the Cook Plant or it may have traveled with the currents from successful hatching in deeper water or further north where larger populations may exist. Since vegetation or some type of structure is required for nest building (Scott and Crossman 1973), it seems unlikely that extensive spawning would occur in any area around Cook, with the exception of the riprap.

Unidentified Larvae --

Occasionally, because of larvae in poor condition or because of inability to identify a larva, some were designated unidentified. Fortunately, this only happened eight times in 1974, and most of these unknown larvae were small, 3.6-7.0 mm (Table C4). There was no pattern as to where these larvae were captured, except that most were caught at beach stations. Since these larvae represented such a small percentage of the total larvae captured, not identifying them with the correct species will not change any conclusions or patterns observed for known species.

Fish Eggs

Data on fish eggs were important in confirming the times and places of spawning by fish species in the area. Eggs were collected in net and sled tows at beach and open water stations around the Cook Plant.

The earliest occurrence of fish eggs in any samples collected during 1973-1974 in net or sled tows (Tables C5, C6 and C7) was on 29 January 1974 at beach stations A (N Cook) and B (S Cook), the only stations sampled in January. Concentrations were 1800 and 2900/1000 m^3 at stations A and B respectively. These eggs were clearly those of burbot as evidenced by their small size, known winter time spawning habits of burbot (Scott and Crossman 1973) and presence of ripe-running burbot in our gill nets set on the same day (see SECTION B - Burbot, for further discussion).

Fish eggs were not collected in early April in both 1973 and 1974 (Tables C5, C6 and C7). April-May was the peak spawning season for rainbow smelt during 1973-1974 when water temperature was 10 C. These temperatures are too cold for alewife spawning. Edsall (1970) found low hatching success and increased (69%) deformities among alewives hatched below 10 C. We thus ruled out alewife as responsible for the eggs found during April-May. Rainbow smelt eggs are sometimes difficult to separate from alewife eggs, because they are identical in color, shape and size (both are 1 mm); however, smelt eggs are demersal and adhesive, attaching to substrate via the short stalk on the egg. Smelt egg size and structure are discussed by Rupp (1965) and drawings are shown in Cooper (1978). On 13 April 1973, smelt eggs were found only at beach stations; none were found at open water stations on 26-29 April. In addition, eggs were collected primarily at night at the beach stations, corroborating our seine data which demonstrated that most ripe-running smelt were caught at night at beach stations. A similar pattern was observed for the 14-18 May 1973 data set; eggs were only collected at beach stations. Lack of eggs at deeper stations and presence of larval smelt in samples collected during the 14-18 May sampling trip suggest strongly that these eggs belonged to late-spawning rainbow smelt; however, some early alewife spawning may also have occurred. In 1974, smelt eggs were again collected exclusively at beach stations (Table C7) during 3, 9 and 24 April. No eggs were collected at any stations during the field trip of 16-20 April 1974. On 2-3 May, large numbers of smelt eggs were again collected at all beach stations in concentrations ranging from 1300 to 13,000/1000 m^3. A few eggs were also collected on 13-19 May at beach station F (Dunes). To verify that most eggs collected during this period were smelt, we examined the eggs collected during the day on 3 May 1974 from beach stations A, B, F. Of the 183 present, 88 were definitely stalked (smelt), 25 were probably stalked (a small hump was present), 38 had no definite stalk and 32 were covered with fungus. We were thus assured that most eggs collected were those of rainbow smelt. Later occurrence of eggs (and larvae) at stations in 1974 compared with 1973, corresponds with the prevailing theme of 1973 being a warm year, causing earlier spawning and greater growth by most fish. (See SECTION B, General Diversity and Distribution of Fish Species.)

Sled tow data for fish eggs during April-May (Table C5) generally confirmed smelt spawning at inshore stations (3 m and less). On 8 May eggs were collected on the bottom at 1.5-, 3- and 6-m stations in low concentrations. On 13 May, even larger concentrations of eggs were discovered, with peak numbers (64,000/1000 m^3) found at station P (1.5 m);

TABLE C5. The number of fish eggs (no/1000 m^3) collected in sled tows during 1974 at beach (A, B, F), transition (P, N) and openwater stations (C, D) in the vicinity of the Cook Plant, southeastern Lake Michigan.

Date	Diel Period	Temp (C)	Station A 1 m N. Cook	Station B 1 m S. Cook	Station F 1 m W. Dunes	Station P 1.5 m Cook	Station N 3 m Cook	Station C 6 m Cook	Station D 9 m Cook
17 Apr	Day	8.0				46	0	0	0
8 May	Day	9.2				715	118	538	0
13 May	Day	9.0-10.0				64,003	18,448	1,795	0
1 Jun	Day	18.0	20,756	956	6,957	17,332	2,168	869	129
11 Jun	Day	14.2-18.6	11,761,000	197,068	7,342,896	18,162,508	106,524	6,961	0
12 Jun	Night	14.5-16.7				11,581	737	16,072	295
20 Jun	Day	15.7-19.2				122	4,917	526	362
25 Jun	Night	15.1			70,485				
26 Jun	Day	15.0-17.3	58,390	18,177	58,491	154,585	4,144	245	412
	Night	12.5-13.0				110,102	22,171	370	366
8 Jul	Day	22.5	338	0	0				
9 Jul	Day	19.8				5,692	6,189	9,619	12,853
10 Jul	Night	17.6			3,890,450	314,996	1,429	3,137	981
11 Jul	Night	16.9	24,713	1,475,665	12,259				
16 Jul	Day	15.8				2,418,094	128,784	0	0
	Night	16.3	26,981	1,478		605,430	2,614	0	890

Table C5. Continued.

Date	Diel Period	Temp (C)	Station A 1 m N. Cook	Station B 1 m S. Cook	Station F 1 m W. Dunes	Station P 1.5 m Cook	Station N 3 m Cook	Station C 6 m Cook	Station D 9 m Cook
17 Jul	Day	22.0	157,935	9,839	12,259				
22 Jul	Night	16.0	90,821	842	10,503				
24 Jul	Day	14.6	141,409	2,113	25,989	49,886	535	0	648
	Night	14.8				10,168	0	205	890
4 Aug	Night	20.0					0		0
5 Aug	Night	19.8	5,164	5,818	152	66,236		180	
6 Aug	Day	22.4	0	16,102	304				
7 Aug	Day	21.0-24.0				1,184	109	3,697	44
14 Aug	Day	18.7	563	11,649	4,827				
	Night	15.8	169	763	9,636				
19 Aug	Day	23.6	529	1,221	0	5,926	284	0	94
	Night	21.7	0	0	0				
20 Aug	Night	19.9				0	0	84	0
9 Sep	Day	19.4	0	0	0	0	0	0	0
	Night	18.4	181	0	0				
11 Sep	Night	19.7					0	0	0
24 Sep	Night	15.6	0	0	0				
25 Sep	Day	17.0	0	0	0				

Table C6. Number of fish eggs (no./1000 m^3) collected in horizontal tows during standard series sampling in 1973 at beach and open water stations in the vicinity of the Cook Plant, southeastern Lake Michigan. ST = step tow.

Station	Tow Depth (m)	14-16 March Day	14-16 March Night	13-29 April Day	13-29 April Night	14-18 May Day	14-18 May Night	18-19 June Day	18-19 June Night	16-20 July Day	16-20 July Night	8-22 August Day	8-22 August Night	6-18 September Day	6-18 September Night
A (1 m)	0	0	0	17000±17000	1400±1400	0	1100±600	0	0	2600±2200	91000±11000	0	240±240	0	2800±2800
B (1 m)	0	0	0	0	500±500	14000±9000	0	25000±22000	53000±34000	1000±1000	2200±130	140±140	550±550	250±0	0
F (1 m)	0	-	-	0	200±200	0	0	0	9000±3200	2500_760	4000000±980000	380±130	350±140	0	5300±5300
C (6 m)	0	-	-	0	0	0	0	0	770	0	0	0	0	0	0
	1	-	-	0	0	0	0	0	660	0	0	0	0	0	0
	2	-	-	0	0	0	0	0	160	0	0	0	0	0	0
	ST	-	-	0	0	0	0	0	0	0	0	0	0	0	0
D (9 m)	0	-	-	0	0	0	0	0	130	0	0	0	0	0	0
	1	-	-	0	0	0	0	170	0	0	0	0	0	0	0
	2	-	-	0	0	0	0	0	0	0	0	0	0	0	0
	ST	-	-	0	0	0	0	0	0	0	0	0	0	0	0
G (6 m)	0	-	-	0	0	0	0	0	43000	0	0	0	0	0	0
	1	-	-	0	0	0	0	200	6000	0	0	0	0	0	0
	2	-	-	0	0	0	0	0	0	0	0	174	0	0	0
	ST	-	-	0	0	0	0	0	10000	0	0	0	0	0	0
H (9 m)	0	-	-	0	0	0	0	0	93	0	0	0	0	0	0
	1	-	-	0	0	0	0	0	8700	0	0	0	0	0	0
	2	-	-	0	0	0	0	0	1200	0	0	0	0	0	0
	ST	-	-	0	0	0	0	0	450	0	0	0	0	0	0
E (21 m)	0	-	-	-		-	-	0		0	-	0	-	-	-
	1	-	-	-	-	-	-	0	-	0	-	0	-	-	-
	2	-	-	-	-	-	-	0	-	0	-	200	-	-	-
	ST	-	-	-			-	0	-	0	-	0	-	-	-
M (6 m)	0		-	-	-	0	0		-	-	-	0	-	-	-
	1		-	-	-	0	0		-	-	-	0	-	-	-
	2	-	-	-	-	0	0	-		-	-	0	-	-	-
	ST	-	-	-	-	0	0	-	-	-	-	0	-	-	-

Table C7. Number of fish eggs (no./1000 m^3) collected in horizontal tows during sampling in 1974 at beach and open water stations in the vicinity of the Cook Plant, southeastern Lake Michigan.

Station	Depth (m)	29 January Day	29 January Night	6-15 March Day	6-15 March Night	3 April Day	3 April Night	9 April Day	9 April Night	24 April Day	24 April Night	18-29 April Day	18-29 April Night
A (1 m)	0	1800±90	-	0	0	0	-	0	-	380±210	-	0	0
B (1 m)	0	2900±2100	-	0	0	0	-	120±120	-	-	-	0	0
F (1 m)	0	-	-	0	0	-	-	-	-	-	-	0	0
C (6 m)	0	-	-	-	-	-	-	-	-	-	-	0	0
	2	-	-	-	-	-	-	-	-	-	-	0	0
	4	-	-	-	-	-	-	-	-	-	-	0	0
	6	-	-	-	-	-	-	-	-	-	-	0	0
D (9 m)	0	-	-	-	-	-	-	-	-	-	-	0	0
	2	-	-	-	-	-	-	-	-	-	-	0	0
	4	-	-	-	-	-	-	-	-	-	-	0	0
	6	-	-	-	-	-	-	-	-	-	-	0	0
	8	-	-	-	-	-	-	-	-	-	-	0	0
G (6 m)	0	-	-	-	-	-	-	-	-	-	-	0	0
	2	-	-	-	-	-	-	-	-	-	-	0	0
	4	-	-	-	-	-	-	-	-	-	-	0	0
	6	-		-	-	-	-	-	-	-	-	0	0
H (9 m)	0	-	-	-	-	-	-	-	-	-	-	0	0
	2	-	-	-	-	-	-	-	-	-	-	0	0
	4	-	-	-	-	-	-	-	-	-	-	0	0
	6	-	-		-	-	-	-	-	-	-	0	0
	8		-		-	-	-	-	-	-	-	0	0
E (21 m)	0	-	-	-	-	-	-	-	-	-	-	-	-
	8	-	-	-	-	-	-	-	-	-	-	-	-
	14	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-				-	-	-	-	-	-

Table C7. Continued.

Station	Depth (m)	2-3 May Day	2-3 May Night	8-9 May Day	8-9 May Night	13-19 May Day	13-19 May Night	22 May Day	22 May Night	1 June Day	1 June Night
A (1 m)	0	1600±300	240±240	0	0	0	0	0	-	240±240	-
B (1 m)	0	1300±160	0	0	0	0	0	0	-	470±120	-
F (1 m)	0	13000±2200	0	-	-	130±130	0	-	-	220±220	
C (6 m)	0	-	-	-	-	0	0	-	-	-	-
	2	-	-	-	-	0	0	-	-	-	-
	4	-	-	-	-	0	0	-	-	-	-
	6	-	-	-	-	0	0	-	-	-	-
D (9 m)	0	-	-	-	-	0	0	-	-	-	-
	2	-	-	-	-	0	0	-	-	-	-
	4	-	-	-	-	0	0	-	-	-	-
	6	-	-	-	-	0	0	-	-	-	-
	8	-	-	-	-	0	0	-	-	-	-
G (6 m)	0	-	-	-	-	0	0	-	-	-	-
	2	-	-	-	-	0	0	-	-	-	-
	4	-	-	-	-	0	0	-	-	-	-
	6	-	-	-	-	0	0	-	-	-	-
H (9 m)	0	-	-	-	-	0	0	-	-	-	-
	2	-	-	-	-	0	0	-	-	-	-
	4	-	-	-	-	0	0	-	-	-	-
	6	-	-	-	-	0	0	-	-	-	-
	8		-	-	-	0	0	-	-	-	-
E (21 m)	0	-	-	-	-	-	-	-	-	-	-
	8	-	-	-	-	-	-	-	-	-	-
	14	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	-

Table C7. Continued.

Station	Depth (m)	4-5 June		11-19 June		25-26 June		8-11 July	
		Day	Night	Day	Night	Day	Night	Day	Night
A (1 m)	0	360±360	30000±27000	140000±13000	420	100000±47000	300000±46000	70±70	380±66
B (1 m)	0	9100±540	50000±7000	14000±5800	0	5300±4700	290000±60000	0	3700±1200
F (1 m)	0	2700±320	90±90	160000±48000	0	64000±41000	88000±59000	140±140	-
C (6 m)	0	-	-	0	1000	-	-	0	1600
	2	-	-	0	550	-	-	0	0
	4	-	-	0	550	-	-	0	280
	6	-	-	0	480	-	-	0	12050
D (9 m)	0	-	-	0	6300	-	-	0	0
	2	-	-	0	980	-	-	0	330
	4	-	-	0	470	-	-	0	0
	6	-	-	0	1700	-	-	0	4200
	8	-		0	1000	-	-	310	0
G (6 m)	0	-	-	0	0	-	-	0	0
	2	-	-	0	330	-	-	0	0
	4	-	-	0	0	-	-	0	0
	6	-	-	0	63	-	-	0	0
H (9 m)	0	-	-	0	34	-	-	0	0
	2	-	-	200	110	-	-	0	0
	4	-	-	0	0	-	-	0	0
	6	-	-	77	0	-	-	0	0
	8	-	-	0	0	-	-	0	0
E (21 m)	0	-	-	0	-	-	-	0	-
	8	-		0	-	-		0	-
	14	-	-	0	-	-	-	0	-
	26	-	-	0	-	-	-	0	-

Table C7. Continued.

Station	Depth (m)	16-17 July		22-24 July		5-6 August		14-15 August		19-20 August		7-9 October	
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
A (1 m)	0	1000±10000	1900±820	0	170±170	0	100±100	340±68	52±52	0	0	0	0
B (1 m)	0	1000±810	320±320	0	0	0	190±190	0	0	0	680±680	0	0
F (1 m)	0	3100±870	6100±1600	300±300	0	50±50	0	2300±450	2000±930	0	490±160	0	0
C (6 m)	0	-	-	-	-	-	-	-	-	0	0	0	0
	2	-	-	-	-	-	-	-	-	0	0	0	0
	4	-	-	-	-	-	-	-	-	0	0	0	0
	6	-	-	-	-	-	-	-	-	43	0	0	0
D (9 m)	0	-	-	-	-	-	-	-	-	0	0	0	0
	2	-	-	-	-	-	-	-	-	0	0	0	0
	4	-	-	-	-	-	-	-	-	0	0	0	0
	6	-	-	-	-	-	-	-	-	0	0	0	0
	8	-	-	-	-	-	-	-	-	0	0	0	0
G (6 m)	0	-	-	-	-	-	-	-	-	0	0	0	0
	2	-	-	-	-	-	-	-	-	170	0	0	0
	4	-	-	-	-	-	-	-	-	0	0	0	0
	6	-	-	-	-	-	-	-	-	170	0	0	0
H (9 m)	0	-	-	-	-	-	-	-	-	0	0	0	0
	2	-	-	-	-	-	-	-	-	0	0	0	0
	4	-	-	-	-	-	-	-	-	0	0	0	40
	6	-	-	-	-	-	-	-	-	0	0	0	0
	8	-	-	-	-	-	-	-	-	0	0	0	0
E (21 m)	0	-	-	-	-	-	-	-	-	0	-	-	-
	8	-	-	-	-	-	-	-	-	0	-	-	-
	14	-	-	-	-	-	-	-	-	0	-	-	-
	20	-	-	-	-	-	-	-	-	0	-	-	-

fewer were collected at the 3-m station ($18,000/1000\ m^3$) and the 6-m station ($1800/1000\ m^3$). None were observed in 9-m samples. Rupp (1965) in his study of rainbow smelt spawning in a Maine lake, indicated that almost all spawning occurred in beach zone waters. Extensive SCUBA searches by Rupp of water up to 6 m, revealed no smelt had spawned that deep. Apparently, currents carried smelt eggs out to 6 m at Cook or some spawning occurred at 6 m.

What are believed to be alewife eggs dominated the catches from June through September (Tables C5, C6 and C7). In 1973, peak numbers of alewife eggs occurred during the 18-19 June field trip. Eggs were generally concentrated at beach stations, with up to $53,000/1000\ m^3$ at station B (S Cook). Some of these eggs may belong to spottail shiner, as spottails are suspected to spawn inshore because of the presence of gravid adults in seines and larvae in sled tows during June-July. Eggs were also collected at all 6- and 9-m open water stations, usually in lower concentrations than at beach stations. An interesting point, which corresponds with our observations of alewives spawning at night, was that in June 1973 at these open water stations, most alewife eggs were found at night. Since alewife eggs are non-adhesive and demersal, eggs which are spawned at night in surface waters should settle to the bottom by the next day, which is the probable reason few were found in day samples.

In July-September 1973, alewife eggs were found almost exclusively at beach stations, suggesting most spawning occurred in the beach zone. No eggs of any species were found past September in 1973. Appearance of alewife eggs at beach stations in September extends the spawning season for alewife at least through August, and possibly into September, if eggs we collected were viable. Many we found were covered with fungus and probably dead.

Patterns in the distribution of alewife eggs observed in 1974 were consistent with those seen in 1973. Alewife eggs were first recorded at beach stations on 1 and 4-5 June 1974 in concentrations up to $50,000/1000\ m^3$. On 11-12 June, alewife eggs were most abundant at beach stations (up to $160,000/1000\ m^3$) and present in high concentrations (maximum of $6300/1000\ m^3$) during the night at open water stations. This trend was also observed in 1973, corroborating their nocturnal spawning behavior. A similar pattern of more eggs collected at night was also noted for the July open water samples. Most eggs were collected at Cook Plant stations (C, D) in 1974; while in 1973 eggs were common at both Cook and Warren Dunes stations. Presence of more eggs in tows at Cook stations during 1974 may be related to turbulence created by the intake and discharge currents which caused eggs to be suspended for longer periods of time. Very little pumping was done in 1973, while considerable testing of pumps was conducted in 1974. During four other sampling periods after 8-11 July, alewife eggs were found in tows at beach stations. A few were also collected in open water tows in August. No other eggs were collected in any samples past August, except at station H (9 m - Dunes) in October when $40/1000\ m^3$ were found in one sample. Origin of these eggs is unknown.

Sled data from 1974 for June through September (Table C5), established that some very large concentrations of alewife (or possibly spottail) eggs existed on the bottom and verified the inshore spawning preference of alewives and spottails. Alewife eggs were first collected in sled tows on 1 June and were present at all stations sampled, from 1 to 9 m. Highest concentrations occurred at beach and 1.5-m stations. On 11 June, which must have been near peak spawning by alewives in 1974, the highest concentrations of eggs ever collected were recorded. At beach stations, between 197 thousand and 11 million eggs/1000 m^3 were collected. Eighteen million eggs/1000 m^3 were found at 1.5 m and numbers declined from 106,000 at 3 m to zero at 9 m. Alewife eggs were still present in substantial numbers at all stations out to 9 m on 26 June. Between 10 and 16 July, alewife eggs were found in numbers up to 3 million/1000 m^3 mainly at beach, 1.5- and 3-m stations.

After 17 July the numbers of eggs found in sled samples declined substantially, to numbers less than 50,000/1000 m^3, except for the 141,000/1000 m^3 found at beach station A (N Cook) on 24 July. On that date some eggs were found at all stations out to 9 m. During August, as was found with net tow data, most occurrences of alewife eggs were at beach stations; up to 11,000/1000 m^3 were present. Some (up to 3700/1000 m^3) were also found on the bottom at open water 6- and 9-m stations.

In September, despite four sampling dates, alewife eggs were only recorded once in sled tows at a concentration of 180/1000 m^3 at beach station F (Dunes). Newly hatched alewife larvae were captured in September, so that at least some eggs present in late August-September were viable.

The eggs of yellow perch have never been collected in our plankton nets during this study. SCUBA divers have observed perch eggs on the Cook Plant riprap during 1975 and 1977 (see Yellow Perch). Yellow perch eggs were also collected once from entrainment samples and were reported to be found once on a gill net and once in a trawl during June 1972. Since yellow perch eggs are demersal and usually laid in special areas, such as habitats with rocks, logs, sticks and other such cover, we do not expect to collect many perch eggs, which are easy to identify because of the large gelatinous matrix in which the hexagonal eggs are found.

Spottail shiner eggs are similar in size to those of the alewife and therefore difficult to distinguish. McCann (1959) reported egg size to be 0.8 mm; our measurements showed 1 mm was a common size. Spottail eggs were collected once by our SCUBA divers from periphyton on the intake structures (see Spottail Shiner). The eggs were adhesive and interwoven among the *Cladophora*. We believe most spottail spawning occurs in the inshore (<3 m deep water) zone of Lake Michigan during June-July. Thus it is indeed possible that some of the eggs collected, particularly those in sled tows at inshore stations, could be those of spottail shiner. Additional effort will be required to resolve this issue.

The eggs of three other species have been located in the vicinity of

the Cook Plant. Sculpin and johnny darter eggs were collected by SCUBA divers from the riprap around the intake and discharge structures in which adults of these species flourished. More discussion of these collections is given under both the appropriate adult and larval species sections in this report. Lastly, during a severe storm in November 1976, lake trout eggs were washed up on the shore in large numbers. We collected a number of these eggs, but could not ascertain their stage of development. No lake trout eggs have ever been collected in any of our other sampling gear or during SCUBA operations, though large numbers of ripe-running adults are collected in our fishing gear. Some adults were also observed by SCUBA divers in the inshore waters around the Cook Plant.

For two other species, trout-perch and carp, because of their abundance in the area and because we have collected many of their larvae, we should have collected their eggs, but to date we have not. For trout-perch, whose long spawning period spans most of June through September, their eggs may be rare in the vicinity and therefore difficult to sample. Carp are abundant around the thermal discharge and have spawned there in recent years as evidenced by collection of many of their larvae in field and entrainment samples. We may have collected their eggs in recent years; further data analysis and careful examination of samples may document the presence of carp eggs in the area.

Fish Larvae Key

The following tables (C8-C18) and drawings (Figs. C24-C33) are an attempt to provide a workable key and description of common fish larvae we have collected during our studies in southeastern Lake Michigan. Gizzard shad (*Dorosoma cepedianum*) larvae were not identified in the area, but were included in the key because of their close similarity to alewife (*Alosa pseudoharengus*) larvae, the fact that adult shad occur in the area, and our desire to provide a more inclusive key.

A summary of meristic and diagnostic characteristics of each species or group (*Cottus* spp.) of larvae derived from our work and summarized from the literature follows the key (Table C8). Illustrations of proto-, meso- and metalarvae are also provided. These drawings were made mainly from specimens we collected in Lake Michigan during 1973-1979. In a few cases larvae from other lakes or drawings from the literature were used to complete the series on a given larval species. Finally, a list of pertinent references and brief synopsis of the literature follows each species so the reader may procure any papers of interest.

The following definitions are provided for terminology used in Tables C8-C18. Postanal myomeres included those behind the myoseptum adjacent to the posterior edge of the vent. An "entire" yolk sac is one that completely fills the gut cavity. Small fins, without rays were described as weakly developed; well developed fins were either large or rayed.

TABLE C8. Working key to the identification of some larval fish occurring in the inshore waters of southeastern Lake Michigan near the D. C. Cook Nuclear Plant.

1)	Vent located distinctly posterior to body midpoint.	2
	Vent at or anterior to body midpoint.	6
2)	Preanal myomeres less than 29	3
	Preanal myomeres more than 28	4
3)	Preanal myomeres 18-22; postanal myomeres 15-18. Postanal length enters preanal length less than 2.0 times. Larva slender, not fusiform. Pigmentation light. Spottail shiner (*Notropis hudsonius*) (Fig. C24).	
	Preanal myomeres 22-24; postanal myomeres 12-16. Postanal length enters preanal length more than 2.0 times. Larva slightly fusiform and robust anteriorly. Heavily pigmented. Carp (*Cyprinus carpio*) (Fig. C25).	
4)	Postanal myomeres usually 8, possibly 9 or 10. Postanal length enters preanal length more than 3.5 times at hatching (or near hatching) lengths. Yolk sac adnate to head at hatching lengths (2.5-4.0 mm TL). Yolk sac positioned within the anterior third of the body.	5
	Postanal myomeres usually 11 or more (11-16). Yolk sac positioned nearly at the point located one-third the distance (TL) from anterior end of larva. Rainbow smelt (*Osmerus mordax*) (Fig. C26).	
5)	Preanal myomeres 37-39. Oil globule absent. Postanal length enters preanal length 4.1-5.1 times at near-hatching lengths (2.5-3.5 mm TL); 3.2-3.8 times for larger larvae and perhaps only 2.1 times for larvae greater than 15 mm TL. Pigmentation usually apparent in larvae greater than 5.0 mm TL. Alewife (*Alosa pseudoharengus*) (Fig. C27).	
	Preanal myomeres 40-44. One large cylindrical, or several small round, oil globules located at posterior end of yolk sac. Postanal length enters preanal	

length 8.0-10.0 times near hatching (4.5 mm TL) lengths; 4.7-5.2 times at 5-6 mm TL, 6.0-7.3 times at 7.5-9.0 mm TL and 4.5-5.3 times at 11-15 mm TL. (Postanal length enters preanal length at least 4.4 times at lengths equal or greater than 15 mm TL). Gizzard shad (*Dorosoma cepedianum*) (Fig. C28).	
6) Vent at or just slightly anterior to body midpoint; postanal length enters preanal length at least 0.7 times but not more than 1.0 times. Length at hatching more than 3.5 mm TL. Finfold not continuous over vent.	7
Vent located near midpoint between first and second quarter of total length. Postanal length enters preanal length about 0.4 times. Finfold continuous over vent (unique to this species). Length at hatching 3.5 mm TL. Burbot (*Lota lota*) (Fig. C29).	
7) Preanal myomeres more than 11, usually more than 13. Oil globule present. Hatching length less than 8.0 mm TL. Pectoral fins small at hatching	8
Preanal myomeres 9-11; postanal myomeres 20. Postanal length enters preanal length 0.7-0.9 times. Larva not less than 8.0 mm. Oil globule absent. Pectoral fins well developed at hatching. Sculpin (*Cottus* spp., *C. bairdi* or *C. cognatus*) (Fig. C30).	
8) Postanal length enters preanal length approximately one times. Larva not strongly fusiform. Stellate melanophores absent from yolk sac.	9
Postanal length enters preanal length slightly less than 1.0 times. Larva robust and strongly fusiform in shape. Numerous large stellate melanophores on ventral aspect of yolk sac. Trout-perch (*Percopsis omiscomaycus*) (Fig. C31).	
9) Head large with a pronounced hump on dorsal aspect, eyes large, snout protruding. Oil globule not obvious, gas bladder absent. Vent slightly decurved. Johnny darter (*Etheostoma nigrum*) (Fig. C32).	
Head and eyes smaller, snout not protruding. Oil globule large and obvious, gas bladder present (during later stages of larval development). Vent strongly decurved. Yellow perch (*Perca flavescens*) (Fig. C33).	

TABLE C9. Some identifying characteristics of spottail shiner (Notropis hudsonius) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1973-1979. See Fig. C24 for illustrations.

Early stages of larval development

1) Approximate length at hatching: 4.7-5.3 mm TL.

2) Myomere count: preanal 18-22; postanal 15-18.

3) Postanal length enters preanal length 1.4-1.6 times.

4) Mouth: non-functional at hatching, becomes small, inferior and slightly oblique by late larval stages.

Gut: yolk sac entire and constricted in the middle at hatching. Oil globule absent.

Body: slender, head of medium size, snout blunt.

Fins: pectoral fins very weakly developed at hatching.

5) Pigmentation: numerous small stellate melanophores on ventral aspect of yolk sac and on ventral aspect of larva proceeding from posterior end of yolk sac to base of caudal fin. Peritoneum above dorsal surface of gas bladder sometimes bearing several small, round melanophores.

Late stages of larval development/early juvenile stage

1) Gas bladder evident by 6-7 mm TL.

2) Spot at base of caudal fin appears later in larval development.

3) Base of anal fin relatively short. Anal rays 7-9.

Synopsis and selected references

The following selected references were useful in identification of spottail shiner larvae. Fish (1929) described a Lake Erie spottail shiner larva using morphometric characteristics such as total length, length to

Table C9. Continued.

vent, body depth, eye diameter and head and mouth shape. Pigmentation was described and a drawing of the larva was provided. Fish (1932) described developmental stages (prolarvae, postlarvae and adults) of spottail shiner from Lake Erie. She discussed spawning and included illustrations of a prolarval and adult spottail shiner. Distribution and ecology, habitat preferences and movement of larval and adult spottail shiners of the Chesapeake Bay region were discussed by Mansueti and Hardy (1967). Spawning, and development of eggs and yolk sac larvae through adult spottail shiners were described and figures detailing larval and adult characteristics were included. Lippson and Moran (1974) described spawning, egg size and characteristics and larval through adult development of the spottail shiner, based on studies conducted in the Potomac River Estuary. Illustrations of the various developmental stages of spottail shiner were included. J. Loos (personal communication, Academy of Natural Sciences of Philadelphia, Philadelphia, Penn.) has provided detailed figures of spottail shiner prolarvae and postlarvae. Dorr et al. (1976) described characteristics of spottail shiner larvae and their relative abundance in southeastern Lake Michigan.

Dorr, J. A. III, D. J. Jude, F. J. Tesar and N. J. Thurber. 1976. Identification of larval fishes taken from the inshore waters of southeastern Lake Michigan near the Donald C. Cook Nuclear Plant, 1973-1975. Pages 61-83 in J. Boreman, ed. Great Lakes fish egg and larvae identification: proceedings of a workshop. Nat. Power Plant Team, Off. Biol. Serv., U.S. Fish Wildl. Serv., Ann Arbor, Mich. 220 pp.

Fish, M. P. 1929. Contributions to the early life histories of Lake Erie Fishes. Bull. Buffalo Soc. Nat. Sci. 14:136-187.

______. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. Bull. U.S. Bur. Fish. 47:293-398.

Lippson, A. J. and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River Estuary. Misc. pub. no. 13. Environ. Techn. Cent., Martin Marietta Corp., Baltimore, Md. 282 pp.

Loos, J. 1977. (Unpubl. figs.) (Fig. 12). Acad. Nat. Sci. Phila., Philadelphia, Pa.

Mansueti, A. J. and J. D. Hardy, Jr. 1967. An atlas of egg, larval, and juvenile stages. Pages 1-202 in E.E. Deubler, Jr., ed. Development of fishes of the Chesapeake Bay region. Part I. Nat. Res. Inst., Univ. Md. College Park, Md.

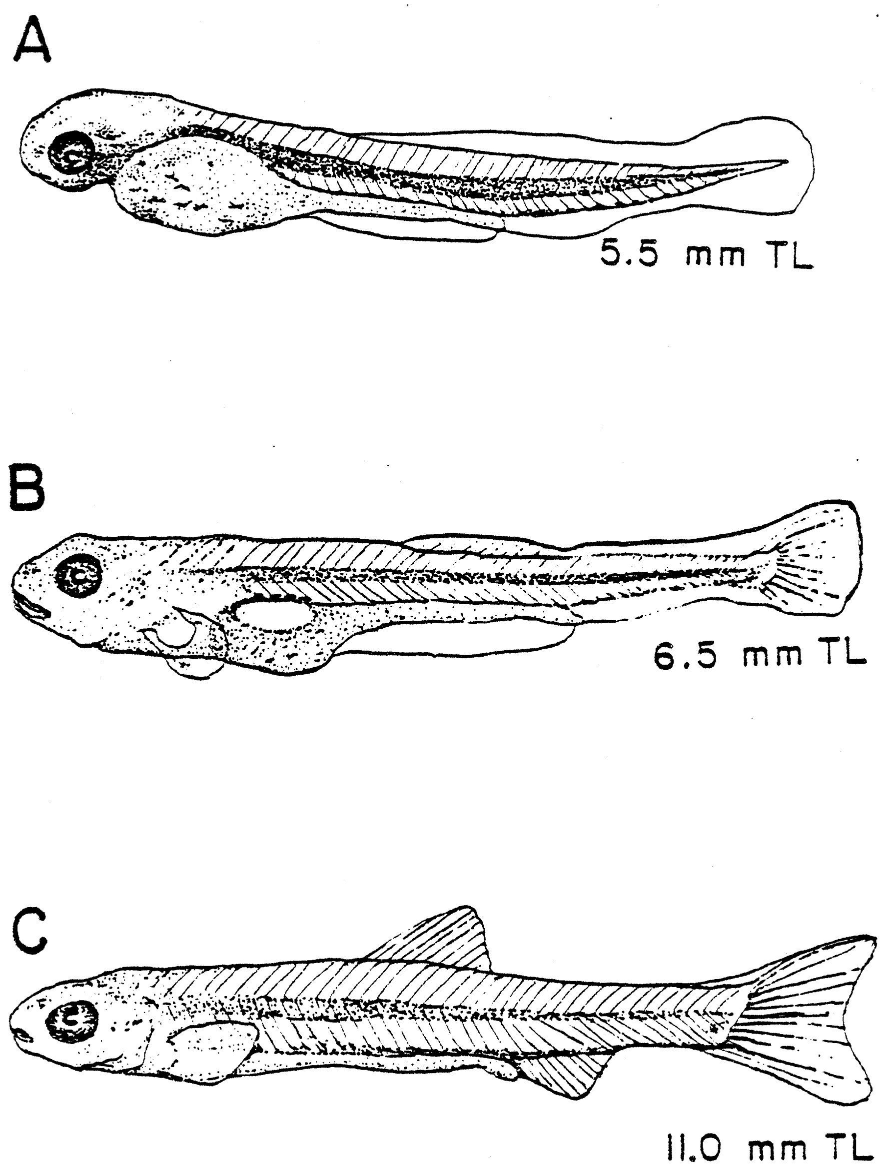

Fig. C24. Generalized illustration of the larvae of the spottail shiner, Notropis hudsonius. (A) protolarva, (B) mesolarva, (C) metalarva. Drawings were made from larvae collected in Lake Michigan during 1973-1979.

TABLE C10. Some identifying characteristics of carp (*Cyprinus carpio*) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1975-1979 and the western basin of Lake Erie, 1975. See Fig. C25 for illustrations.

Early stages of larval development

1) Approximate length at hatching: 3.0-3.5 mm TL.

2) Myomere count: preanal 22-24; postanal 12-16.

3) Postanal length enters preanal length at least 2.5 times at hatching; less (2.1 times) at later length stages (9.5 mm TL).

4) Mouth: non-functional at hatching, becomes horizontal and subterminal by 9.0 mm TL.

Gut: yolk sac small and not entire, oil globule absent.

Body: slender and fragile but slightly fusiform.

Fins: pectoral fins weakly developed at hatching.

Other: larvae small at hatching but cephalic region robust in appearance.

5) Pigmentation: numerous round melanophores on dorsal surface of head and scattered down dorsal midline. Numerous melanophores on peritoneum dorsal to gas bladder. Band of melanophores along lateral midline from caudal end to immediately posterior of operculum where band diverges to form a horizontal "Y" with a branch above and below operculum. Single line of melanophores along ventral midline from posterior end of yolk sac to vent; double line from vent to caudal fin base.

Late stages of larval development/early juvenile stage

1) Base of anal fin short. Anal fin rays: three spinous, five soft.

2) Weberian apparatus discernible via clearing (trypsin) and staining (alcian blue) by 9.0 mm TL, perhaps earlier.

Synopsis and selected references

The following selected references were useful in identifying carp larvae. Smallwood and Smallwood (1931) described and provided illustrations of the development of carp larvae from hatching onward, with an emphasis on behavioral adaptations, intestinal growth and feeding. Fish (1932) described

Table C10. Continued.

in detail developmental stages of carp larvae (10-30 mm) collected from Lake Erie. Okado (1959-1960) studied spawning, embryonic development and larval carp growth; illustrations of eggs, prolarval, postlarval and adult carp were given. McCrimmon and Swee (1967) showed scale formation on carp in relation to growth and development. A table summarizing developmental and morphometric characteristics with respect to total length of carp, ranging in size from 5 to 33 mm, was included. Mansueti and Hardy (1967) discussed distribution and ecology of carp in the Chesapeake Bay region and described habitat preferences and movements of carp larvae and adults. Spawning and development of eggs, yolk sac larvae, postlarvae and adult carp were described and figures detailing egg stages, emerging embryos, larval and adult characteristics were provided. May and Gasaway (1967) gave a brief description of carp larvae and included a photograph of an 8-mm specimen. Taber (1969) compared carp larvae with other cyprinid lavae, distinguishing the carp by its large size, large and opaque yolk sac and strong pigmentation in postlarvae. Figures of prolarval, postlarval and adult carp were presented. Verma (1970) described 30 morphological stages in the development of carp. Twenty stages were associated with egg and embryonic development; the remaining 10 stages detailed prolarval and postlarval developmental stages. Diagrams of the various developmental stages supplemented the written descriptions. Lippson and Moran (1974) described spawning, egg size and characteristics and larval through adult development of the carp, based on studies conducted in the Potomac River Estuary. Drawings of the various developmental stages of carp were included. Hogue et al. (1976) described carp larvae collected from the Tennessee River Valley; included were morphometric characteristics, development and a photograph of a postlarva.

Fish, M. P. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. U.S. Bur. Fish. Bull. 47:293-398.

Hogue, J. J., Jr., R. Wallus and L. K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Tech. Note B19. Div. For. Fish. Wildl. Dev., T.V.A. Norris, Tenn. 67 pp.

Lippson, A. J. and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River Estuary. Misc. pub. no. 13. Environ. Tech. Cent., Martin Marietta Corp., Baltimore, Md. 282 pp.

Mansueti, A. J. and J. D. Hardy, Jr. 1967. An atlas of egg, larval and juvenile stages. Pages 1-202 in E.E. Deubler, Jr., ed. Development of fishes of the Chesapeake Bay region. Part I. Nat. Res. Inst., Univ. Md., College Park, Md.

Table C10. Continued.

May, E. B. and C. R. Gasaway. 1967. A preliminary key to the identification of larval fishes of Oklahoma, with particular reference to Canton Reservoir including a selected bibliography. Okla. Fish. Res. Lab. Bull. No. 5. 33 pp. (Figs. 15-17).

McCrimmon, H. R. and U. B. Swee. 1967. Scale formation as related to growth and development of young carp, Cyprinus carpio L. J. Fish. Res. Bd. Can. 24:47-51.

Nordqvist, H. 1914. Bidrag till kannedomen om vara sotvattens-fiskars larvstadier. Arkiv for Zoologi 9(4):1-49. (Figs. 12-14).

Okado, Y. 1959-60. Studies on the freshwater fishes of Japan. Prefectural Univ. Mie Tsu, Mie Prefecture, Japan 4(1):1-860.

Smallwood, W. M. and M. L. Smallwood. 1931. The development of the carp, Cyprinus carpio. J. Morphol. 52:217-219.

Taber, C. 1969. The distribution and identification of larval fishes in the Buncombe Creek arm of Lake Texoma with observations on spawning habits and relative abundance. Ph.D. Thesis. Univ. Okla., Norman, Okla. 120 pp.

Verma, P. 1970. Normal stages in the development of Cyprinus carpio var. communis L., Acta. Biol. Acad. Sci. Hung. 21:207-219.

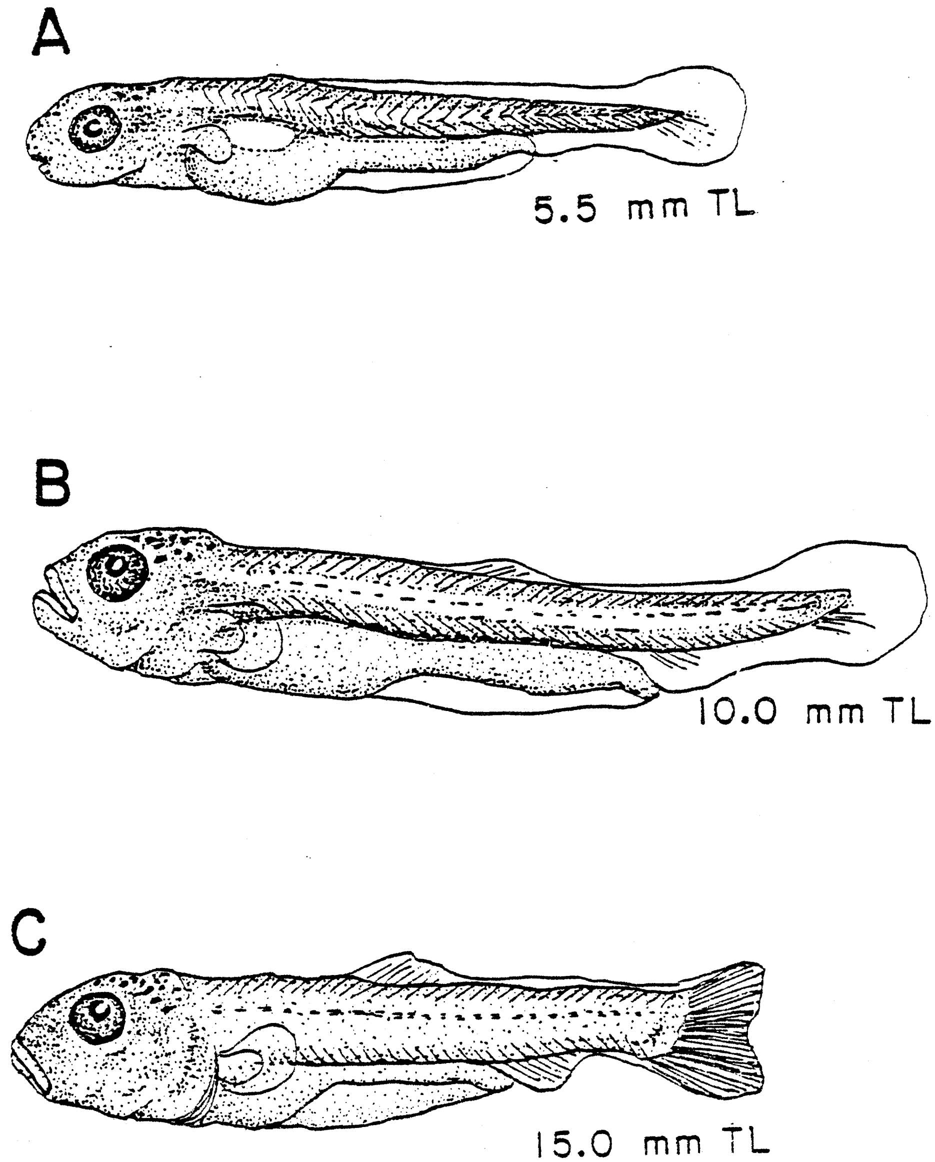

Fig. C25. Generalized illustration of the carp, *Cyprinus carpio*. (A) protolarva, (B) mesolarva, (C) metalarva. Drawings of protolarvae were made from larvae collected in Lake Michigan during 1973-1979. Meso and metalarvae drawings were made from Lake Erie specimens.

TABLE C11. Some identifying characteristics of rainbow smelt (*Osmerus mordax*) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1973-1979. See Fig. C26 for illustrations.

Early stages of larval development

1) Approximate length at hatching: 4.5 mm TL.

2) Myomere count: preanal 40-42 (range in literature 35-42): postanal 18-21 (range in literature 11-16).

3) Postanal length enters preanal length 2.0-2.9 times.

4) Mouth: non-functional at hatching, becomes large, terminal and oblique by late stages of larval development.

Gut: yolk sac small, containing an anterior oil globule. Yolk sac not adnate to head. Yolk sac positioned near the point located one-third the distance (TL) from anterior end of larva.

Body: long and very slender (filiform). Head small, snout blunt.

Fins: pectoral fins very weakly developed at hatching.

5) Pigmentation: paired row of elongate melanophores on ventral aspect of larva between pectoral fins and pelvic fin buds, becoming a single row between pelvic fin buds and vent. Several (often three) widely-spaced elongate melanophores may be present on ventral aspect between vent and base of caudal fin.

Late stages of larval development/early juvenile stage

1) Pelvic fin buds quite obvious as a distinct swelling on ventral aspect near midpoint of larva.

2) Base of anal fin relatively long. Anal fin rays 13-16.

3) Dorsal fin inserts almost directly over pelvic fins. Dorsal fin rays 8-11.

4) Jaw teeth may be evident on premaxillary and dentary bones.

5) Adipose fin may not become evident until larva is 20-35 mm TL.

Table C11. Continued.

Synopsis and selected references

The following selected references were useful in identification of rainbow smelt larvae. Kendall (1927) discussed the characteristics of eggs, hatching, larval development and stocking of European smelt based on literature and his own experience collecting smelt eggs and larvae from small brooks and lakes in Maine. He included illustrations of eggs and larvae. Bigelow (1953) described behavior and development of smelt in the Atlantic Ocean. Dorr et al. (1976) described characteristics of smelt larvae and their relative abundance in southeastern Lake Michigan. Cooper (1977) cultured artificially fertilized rainbow smelt eggs and studied their development from embryonic through juvenile stages. Written descriptions of rainbow smelt protolarvae (5 mm), mesolarvae (14 mm), metalarvae (22.5 mm) and juveniles (36.0 mm) were included along with tables summarizing various meristic characteristics and figures depicting developing eggs and larvae. Cooper also compared the developmental morphology of alewife and gizzard shad larvae with rainbow smelt larvae, and identified important characteristics he used to distinguish between these three larval species.

Bigelow, H. B. and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. Fish. Bull. 53(74):1-577.

Cooper, J. E. 1978. Identification of eggs, larvae and juveniles of the rainbow smelt, _Osmerus mordax_, with comparisons to larval alewife, _Alosa pseudoharengus_, and gizzard shad, _Dorosoma cepediamum_. Trans. Amer. Fish. Soc. 107:56-62.

Dorr, J. A., III, D. J. Jude, F. J. Tesar and N. J. Thurber. 1976. Identification of larval fishes taken from the inshore waters of southeastern Lake Michigan near the Donald C. Cook Nuclear Plant, 1973-1975. Pages 61-82 _in_ J. Boreman, ed. Great Lakes fish egg and larvae identification: proceedings of a workshop. Nat. Power Plant Team, Off. Biol. Serv., U.S. Fish Wild. Serv., Ann Arbor, Mich.

Kendall, W. C. 1927. The smelts. U.S. Bur. Fish. Bull. 42:217-375.

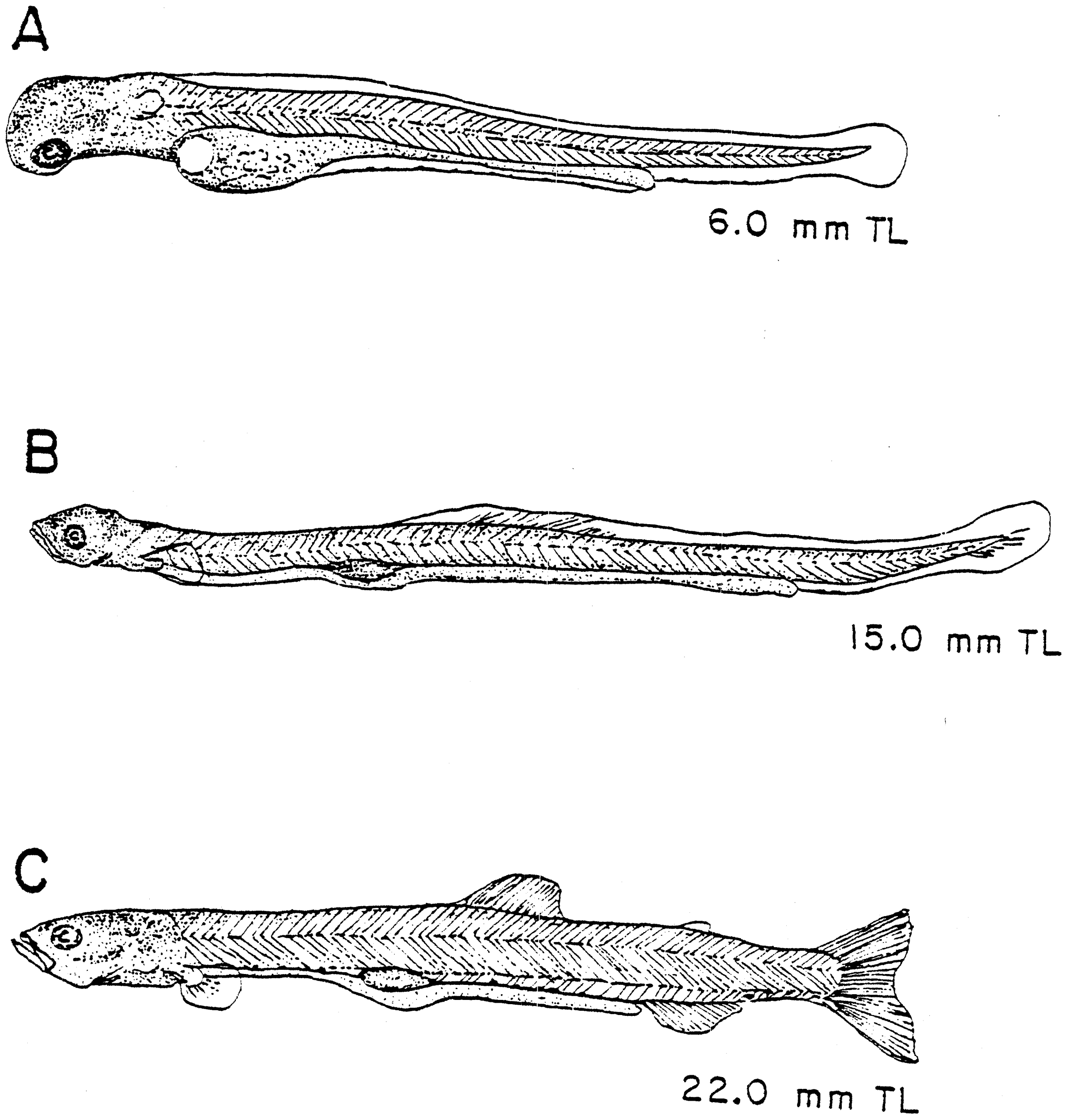

Fig. C26. Generalized illustration of the larvae of the rainbow smelt, Omerus mordax. (A) protolarva, (B) mesolarva, (C) metalarva. Drawings were made from larvae collected in Lake Michigan during 1973-1979.

TABLE C12. Some identifying characteristics of alewife (*Alosa pseudoharengus*) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1973-1979. See Fig. C27 for illustrations.

Early stages of larval development

1) Approximate length at hatching: 2.5-3.5 mm TL.

2) Myomere count: preanal 37-39; postanal 8-10.

3) Postanal length enters preanal length 3.2-3.8 times; 4.1-5.1 times for larvae less than 24-h old.

4) Mouth: non-functional and barely evident at hatching, becomes large, terminal and oblique (upturned) by late larval stages.

Gut: yolk sac small, oval and not entire; oil globule absent.

Body: long and very slender (filiform). Larvae very small and fragile at hatching; head small, snout blunt.

Fins: pectoral fins barely evident at hatching, remaining weakly developed well into later larval stages.

Other: yolk sac adnate to head - head flexed ventrally over a yolk sac at hatching, remaining so for approximately 24 h following hatching (2.5-4.0 mm TL).

5) Pigmentation: paired row of elongate melanophores on ventral aspect of larvae between pectoral fins and pelvic fin buds, constricting to a narrowly spaced, paired row between pelvic fin buds and vent. Pigmentation often not evident at or immediately following hatching.

Late stages of larval development/early juvenile stage

1) Postanal length may enter preanal length only 2.1 times (approximately).

2) Base of anal fin relatively long. Anal fin rays approximately 18.

3) Dorsal fin inserts behind pelvic fins. Dorsal fin rays 12-16.

4) Scutes may or may not be evident at 22-25 mm TL.

Table C12. Continued.

Synopsis and selected references

The following selected references were useful in identifying alewife larvae. Ryder (1885) described spawning habits and prolarval characteristics of alewife, including a drawing of an alewife prolarva. Norden (1967) described the development and identification of larval alewife collected from Lake Michigan. He discussed features such as numbers of myomeres and fin rays present for prolarval through postlarval stages. Distinguishing characteristics of alewife larvae were compared with other species of larval fish found in Lake Michigan with emphasis on smelt and gizzard shad. Norden (1968) described feeding of larval alewife in Lake Michigan.

Mansueti and Hardy (1967) discussed the distribution, ecology, habitat preferences and movement of larval through adult fish in the Chesapeake Bay region. Spawning and development of eggs and yolk sac larvae through adult alewife were described and figures detailing egg stages, emerging embryo, larval and adult characteristics were given. Lippson and Moran (1974) described spawning, egg size and characteristics and larval through adult stages of development of the alewife, based on studies in the Potomac River Estuary. Drawings of the various developmental stages of alewife were also included. Dorr et al. (1976) described characteristics of alewife larvae in Lake Michigan. Lam and Roff (1977) discussed identification of larval alewife based on meristic and morphometric characteristics.

Separation of 10-25 mm alewife and rainbow smelt was difficult. Dorr et al. (1976) and Cooper (1978) suggest a combination of characters including position of yolk sac relative to head, numbers of preanal and postanal myomeres and possible presence or absence of an oil globule, jaw teeth and scutes may facilitate separation of these species.

Dorr, J. A., III, D. J. Jude, F. J. Tesar and N. J. Thurber. 1976. Identification of larval fishes taken from the inshore waters of southeastern Lake Michigan near the Donald C. Cook Nuclear Plant, 1973-1975. Pages 61-83 _in_ J. Boreman, ed. Great Lakes fish egg and larvae identification: proceedings of a workshop. Nat. Power Plant Team, Off. Biol. Serv., U.S. Fish Wildl. Serv., Ann Arbor, Mich.

Lam, C. N. H. and J. C. Roff. 1977. A method for separating alewife _Alosa pseudoharengus_ from gizzard shad _Dorosoma cepediaumum_ larvae. J. Great Lakes Res. 3:313-316.

Lippson, A. J. and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River Estuary. Misc. Publ. no. 13. Environ. Tech. Cent., Martin Marietta Corp., Baltimore, Md. 282 pp.

Table C12. Continued.

Mansueti, A. J. and J. D. Hardy, Jr. 1967. An atlas of egg, larval and juvenile stages. Pages 1-202 in E. E. Deubler, Jr., ed. Development of fishes of the Chesapeake Bay region. Part I. Nat. Res. Inst., Univ. Md., College Park, Md.

Norden, C. R. 1967. Development and identification of the larval alewife, *Alosa pseudoharengus* (Wilson), in Lake Michigan. Proc. 10th Conf. Great Lakes Res., Int. Assoc. Great Lakes Res. Pages 70-78.

______. 1968. Morphology and food habits of the larval alewife, *Alosa pseudoharengus* (Wilson), in Lake Michigan. Proc. 11th Conf. Great Lakes Res., Int. Assoc. Great Lakes Res. Pages 103-110.

Ryder, J. A. 1887. Development of osseous fishes, including marine and freshwater forms. U.S. Comm. Fish. Rept. 13(1885):489-604. (30 pls.)

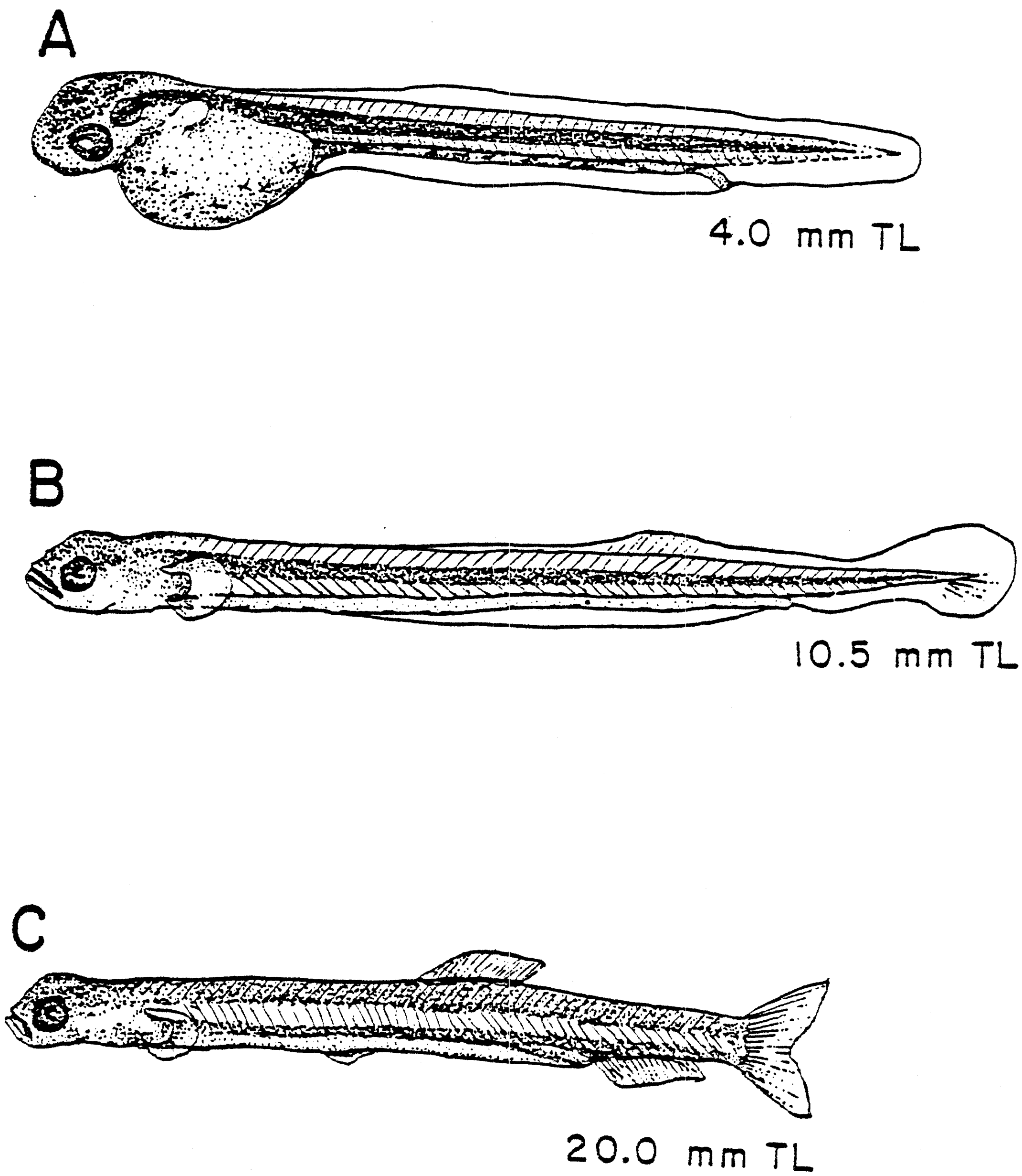

Fig. C27. Generalized illustration of the larvae of the alewife, *Alosa pseudoharengus*. (A) protolarva, (B) mesolarva, (C) metalarva. Drawings were made from larvae collected in Lake Michigan during 1973-1979.

Table C13. Some identifying characteristics of gizzard shad (*Dorosoma cepedianum*) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1977-1979 and the western basin of Lake Erie, 1975. See Fig. C28 for illustrations.

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1) Approximate length at hatching: 3.3 mm.

2) Myomere count: preanal 40-44; postanal 6-8 (for 4.5-15.0 mm TL).

3) Postanal length enters preanal length 8-10 times at 4.5 mm TL, 4.7-5.2 times at 5.0-6.0 mm TL, 6.0-7.3 times at 7.5-9.0 mm TL and 4.4-5.3 times at 11.0-15.0 TL. Postanal length enters preanal length at least 4.4 times at lengths equal or greater than 15 mm TL.

4) Mouth: non-functional and barely evident at hatching; becomes large, terminal and oblique (upturned) by late larval stages.

Gut: yolk sac small, cylindrical and not entire at length stages greater than 4.5 mm TL. One large or several small oil globules present at posterior end of yolk sac. Gut very long, relative to total length.

Body: long and very slender (filiform). Larvae very small and fragile at hatching; head small, snout blunt.

Fins: pectoral fin barely evident and not rayed at 4.5 mm TL, remaining weakly developed well into later larval stages.

Other: Yolk sac adnate to head - head flexed ventro-posteriorly over yolk sac at hatching; head not flexed at 4.5 mm TL.

5) Pigmentation: generally, larvae are unpigmented. At lengths between 4.5-15.0 mm TL, eye may be unpigmented or only lightly pigmented. Body pigment usually absent at 4.5-15.0 mm TL but if present occurs as a single paired row of elongate melanophores on the lateral aspects of the gut extending from the gular region to the body midpoint; from the body midpoint to vent a double paired row of elongate melanophores occurs on the lateral and ventral aspects of the gut, respectively. Scattered small melanophores may also be present on lower half of caudal fin. Pigmented larvae were only observed at length stages beyond 7.5 mm TL.

Table C13. Continued.

<u>Selected references</u>

Bodola, A. 1966. Life history of gizzard shad, *Dorosoma cepedianum* (LeSueur), in western Lake Erie. U.S. Fish. Wildl. Serv., Fish. Bull. 65:391-425.

Hogue, J. J., Jr., R. Wallus and L. K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Tech. Note B19 Div. For. Fish. Wildl. Dev. T.V.A. Morris, Tenn. 67 pp.

Jones, P. W., F. D. Martin and J. D. Hardy, Jr. 1978. Development of fishes of the Mid-Atlantic Bight, an atlas of egg, larval and juvenile stages, volume 1 Acipenseridae through Ictaluridae. Power Plant Proj., Off. Biol. Serv., U.S. Fish Wildl. Serv. Washington D.C. 366 pp.

Lippson, A. J. and R. L. Moran. 1974. Manual for identification of fishes of the Potomac River Estuary. Misc. pub. no. 13. Environ. Tech. Cent. Martin Marietta Corp. Baltimore, Md. 282 pp.

Mansueti, A. J. and J. D. Hardy, Jr. 1967. An atlas of egg, larval, and juvenile stages. Pages 1-202 *in* E. E. Deubler, Jr. ed. Development of fishes of the Chesapeak Bay region. Part I. Nat. Res. Inst., Univ. Md., College Park, Md.

May, E. B. and C. R. Gasaway. 1967. A preliminary key to the identification of larval fishes of Oklahoma, with special reference to Canton Reservoir, including selected bibliography. Okla. Fish. Res. Lab. Bull. No. 5. 33 pp. (Figs. 10 and 11).

Miller R. R. 1960. Systematics and biology of the gizzard shad (*Dorosoma cepedianum*) and related fishes. U.S. Fish. Wildl. Serv., Fish. Bull. 173:371-392.

Taber, C. A. 1969. The distribution and identification of larval fishes in the Buncombe Creek arm of Lake Texoma with observations on spawning habits and relative abundance. Ph.D. Thesis. Univ. Okla. Norman, Okla. 120 pp.

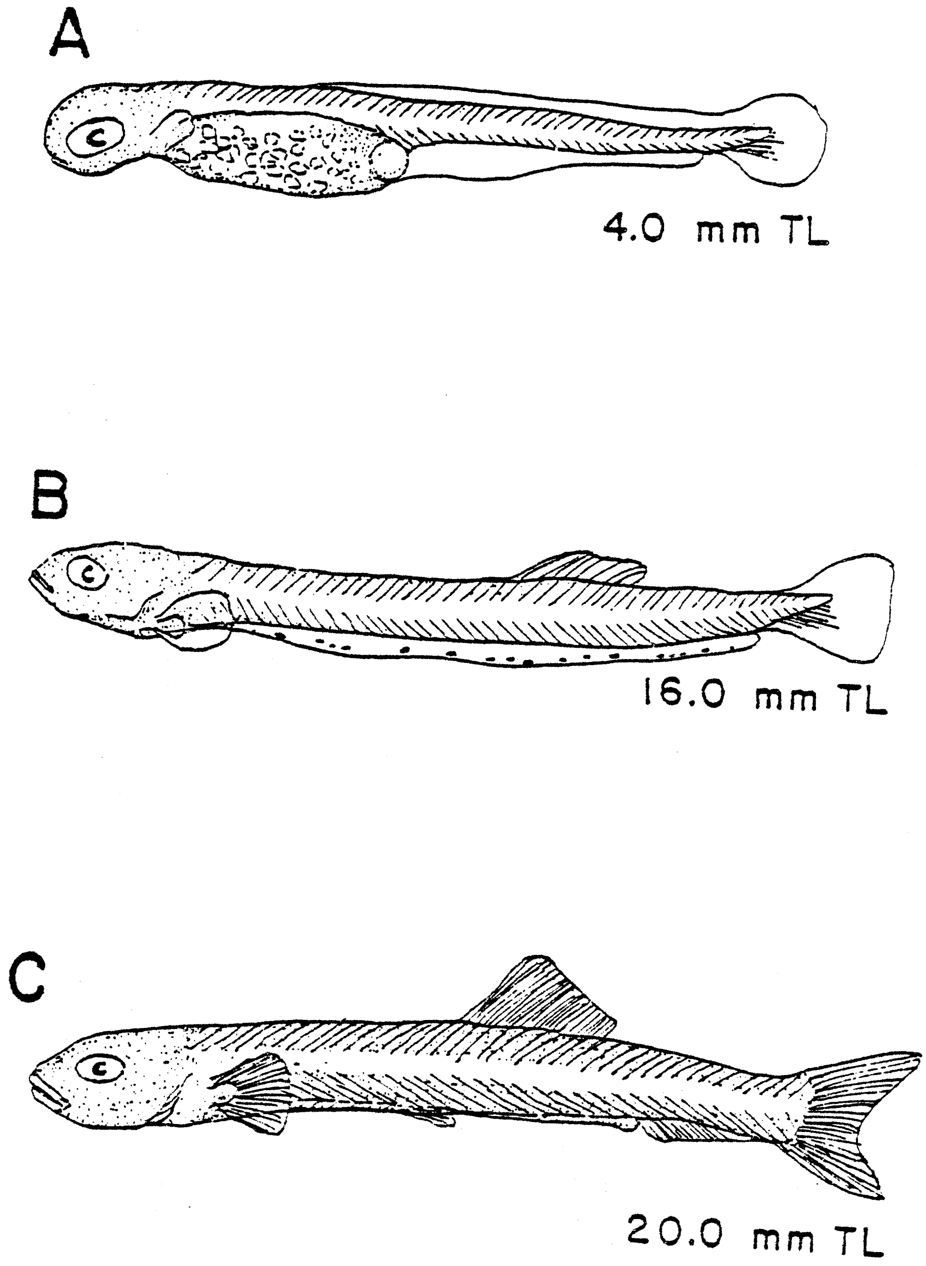

Fig. C28. Generalized illustration of larvae of the gizzard shad, Dorosoma cepedianum. (A) protolarva, (B) mesolarva, (C) metalarva. Drawing of protolarva was made from larvae collected in Lake Michigan during 1973-1979. Meso- and metalarvae were made from Lake Erie specimens.

TABLE C14. Some identifying characteristics of burbot (*Lota lota*) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1975-1979 and from Oneida Lake, 1974. See Fig. C29 for illustrations.

Early stages of larval development

1) Approximate length at hatching: 3.5 mm TL.

2) Myomere count. preanal 12-14; postanal 42-45.

3) Postanal length enters preanal length 0.4 times from hatching through 9.5 mm TL stages.

4) Mouth: non-functional at hatching, becomes large horizontal and terminal by 9.5 mm TL.

Gut: yolk sac large and not entire; oil globule present at hatching.

Body: long and slender (filiform); larvae very small at hatching; head large, snout blunt.

Fins: pectoral fins small and weakly developed at hatching, large and well developed by 9.5 mm TL.

Other: finfold continuous over vent, vent appears to exit dorsal and to the right side of finfold midline.

5) Pigmentation: unresolved. Some specimens examined were nearly transparent at hatching and others examined at 9.5 mm TL were also quite unpigmented. Other specimens had 7-8 large round melanophores on dorsal surface of head, 10-15 small round melanophores on peritoneum dorsal to gas bladder and a single row along ventral and dorsal midline posterior to yolk sac.

Late stages of larval development/early juvenile stage

1) Larva distinctly gadid in shape and appearance of head and fins by 9.5 mm TL.

Synopsis and selected references

The following selected references were useful in identification of burbot larvae. Fish (1929, 1930, 1932) examined Lake Erie burbot eggs, larvae and adults and described spawning, egg development, prolarval and postlarval characteristics and the adult stage of burbot. Burbot larvae, juveniles and adults ranging in size from 3.5 to 30.5 mm were described and drawings of prolarvae and postlarvae included. Key characteristics used to

Table C14. Continued.

identify burbot larvae were: total length, length to vent, head length, snout length, eye diameter, body depth, total preanal and postanal myomeres, yolk sac shape, fin development and pigmentation. Muth (1973) incubated fertilized burbot eggs in the laboratory and observed growth and development, before and after hatching. Muth provided written descriptions of burbot larvae and a series of photographs taken during embryonic and larval stages of development.

Fish, M. P. 1929. Contributions to the early life histories of Lake Erie Fishes. Bull Buffalo Soc. Nat. Sci. 14:136-187.

______. 1930. Contributions to the natural history of the burbot, *Lota maculosa* (LeSueur). Bull. Buffalo Soc. Nat. Sci. 15:5-20.

______. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. Bull. U.S. Bur. Fish. 47:293-398.

Kanansky, W. J. 1928. Zur morphologie der brut von *Lota lota* L. Zool. Anz. Leipzig 79:143-148. (Figs. 1-4).

Muth, K. 1973. Population dynamics and life history of burbot, *Lota lota* (Linnaeus), in Lake of the Woods, Minnesota. Ph.D. Thesis. Univ. Minn., St. Paul, Minn. 164 pp.

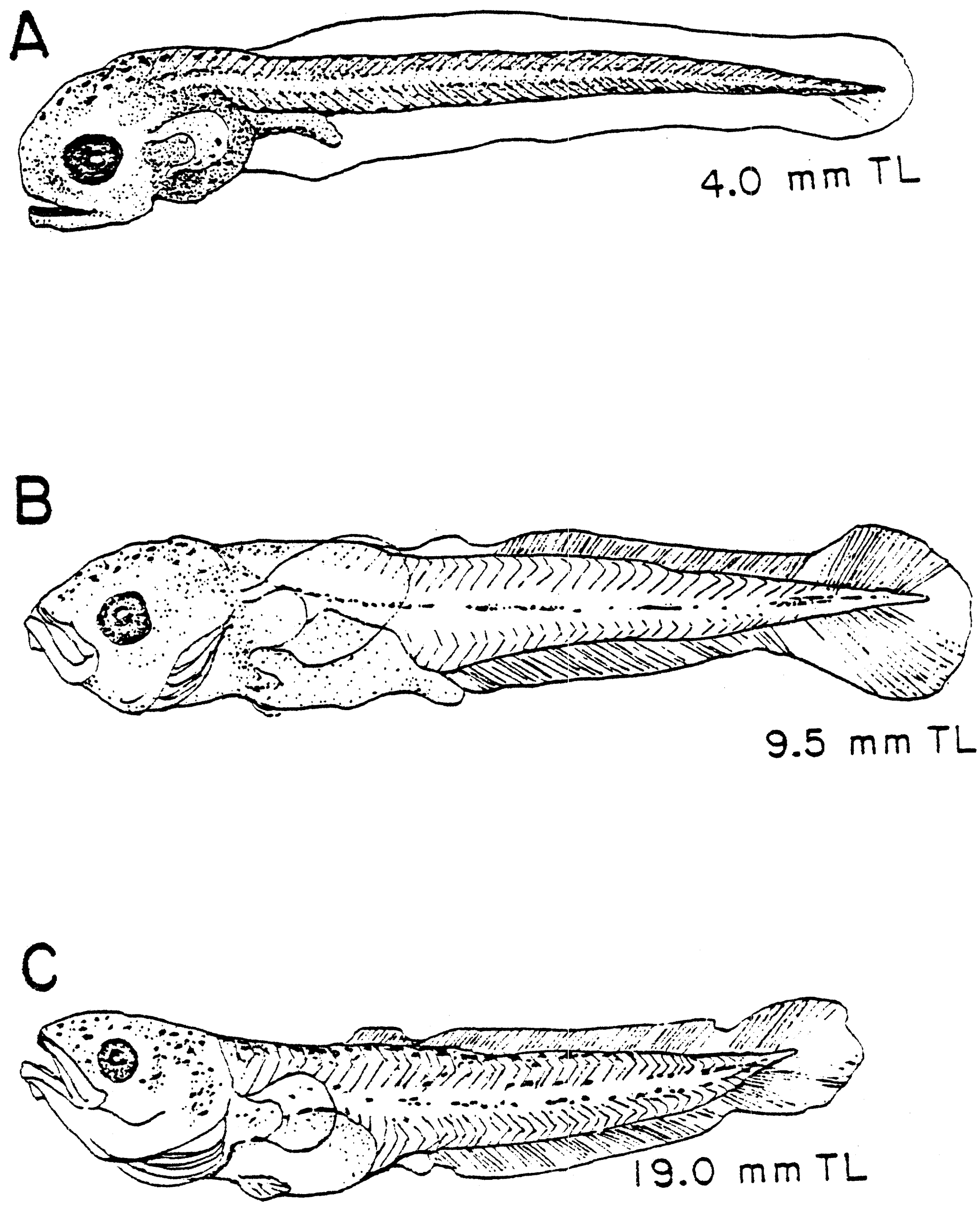

Fig. C29. Generalized illustration of the burbot. Lota lota.
(A) protolarvae, (B) mesolarva, (C) metalarva. Drawing of the protolarva was made from larvae collected in Lake Michigan during 1973-1979. The mesolarvae was drawn from Lake Oneida specimens and the metalarvae was redrawn from Fish (1930).

TABLE C15. Some identifying characteristics of sculpin (Cottus spp. - C. bairdi or C. cognatus) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1974-1979. See Fig. C30 for illustrations.

Early stages of larval development

1) Approximate length at hatching: 8.0 mm TL.

2) Myomere count: preanal 9-11; postanal 20.

3) Postanal length enters preanal length 0.7-0.9 times.

4) Mouth: well developed at hatching, becomes large, inferior and horizontal by late larval stages.

Gut: large, entire yolk sac containing an oil globule.

Body: robust, thick and wide. Head large, snout blunt.

Fins: pectoral fins well developed at hatching; ray development occurs shortly after hatching.

Other: larva is large and well developed at hatching; assumption of juvenile characteristics occurs with only an approximate 1.2 mm increase in total length.

5) Pigmentation: a few small round scattered melanophores are evident at hatching.

Synopsis and selected references

The following selected references were useful in identification of sculpin larvae. Fish (1929, 1932) studied and included drawings of mottled sculpin larvae that were 6.0 and 10.0 mm TL. Key characteristics used were: total length, length to vent, body depth, eye diameter, total preanal and postanal myomeres, fin development and pigmentation. Dorr et al. (1976) described characteristics of cottid larvae collected in Lake Michigan.

Dorr, J. A., III, D. J. Jude, F. J. Tesar and N. J. Thurber. 1976. Identification of larval fishes taken from the inshore waters of southeastern Lake Michigan near the Donald C. Cook Nuclear Plant, 1973-1975. Pages 61-82 in J. Boreman ed. Great Lakes fish egg and larvae identification: proceedings of a workshop. Nat. Power Plant Team. Off. Biol. Serv., U.S. Fish Wildl. Serv., Ann Arbor, Mich.

Table C15. Continued.

Fish, M. P. 1929. Contributions to the early life histories of Lake Erie fishes. Bull. Buffalo Soc. Nat. Sci. 14:136-187.
______. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. Bull. U.S. Bur. Fish. 47:293-398.

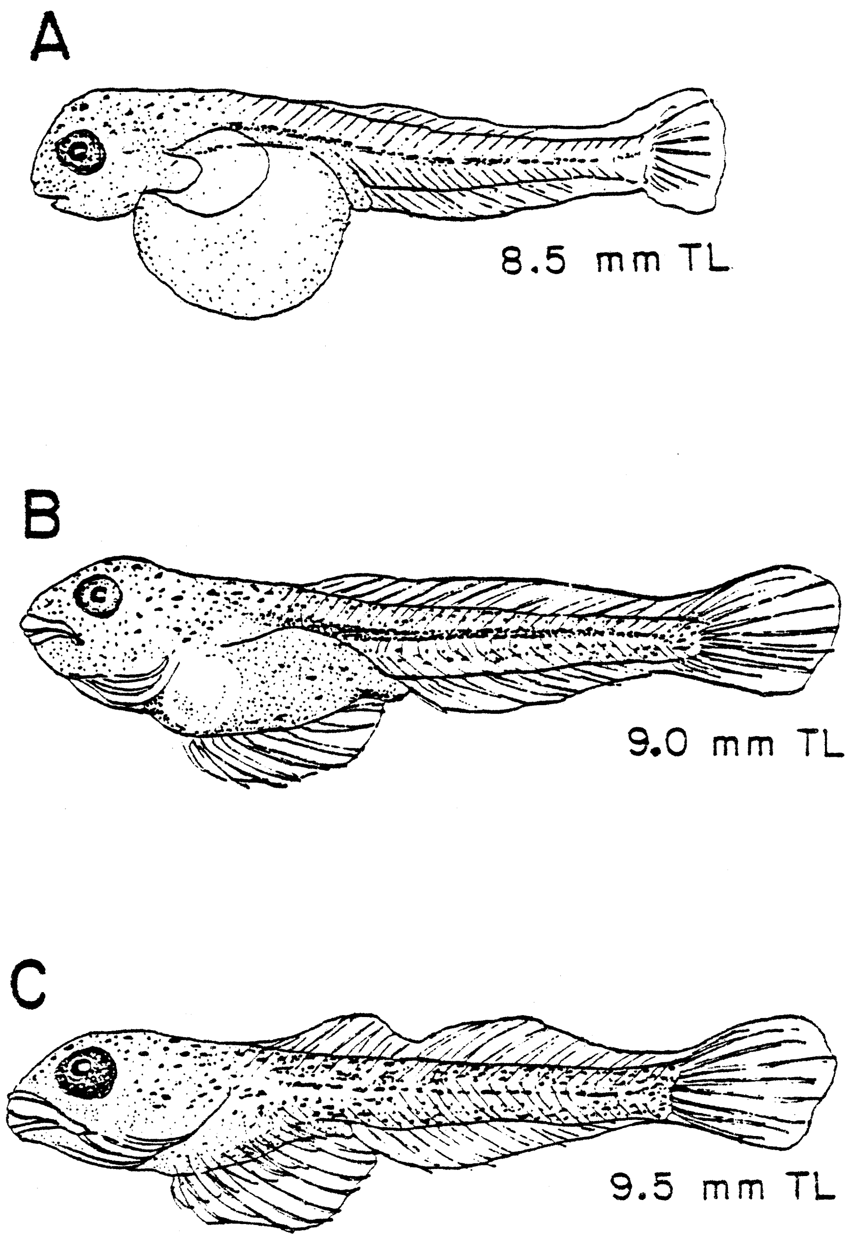

Fig. C30. Generalized illustration of the larvae of Cottus spp. (C. bairdi or C. cognatus). (A) early mesolarva, little yolk absorbed, (B) late mesolarva, yolk partially absorbed, (C) metalarva. Drawings were made from larvae collected in Lake Michigan during 1973-1979.

TABLE C16. Some identifying characteristics of trout-perch (*Percopsis omiscomaycus*) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1974-1978. See Fig. C31 for illustrations.

Early stages of larval development

1) Approximate length at hatching: 5.5 mm TL.

2) Myomere count: preanal 14 (range in literature 12-19); postanal 21 (range in literature 18-22).

3) Postanal length enters preanal length 0.8 times.

4) Mouth: non-functional at hatching, becomes large, terminal and oblique by late larval stages.

Gut: yolk sac large, not entire and containing an oil globule at hatching; vent prominent.

Body: robust and fusiform. Head large, snout projecting, eye often oval and small relative to size of head.

Fins: pectoral fins weakly developed at hatching, remaining so through at least 8 mm TL.

Other: urostyle oblique at 6 and 8 mm TL.

5) Pigmentation: numerous large, prominent, stellate melanophores on ventral aspect of yolk sac. Single row of small, round melanophores on ventral aspect of larva from vent to base of caudal fin. Dorsal aspect of stomach covered with a dense mat of small subsurface melanophores.

Late stages of larval development/early juvenile stage

1) Base of anal fin short. Anal rays 5-8.

Synopsis and selected references

The following selected references were useful in identification of trout-perch larvae. Fish (1929, 1930, 1932) described and provided drawings of trout-perch (6-39.5 mm) collected in Lake Erie. She studied larval development from embryonic through adult stages and briefly discussed spawning. Key characteristics used were: total length, length to vent, body depth, eye diameter, total preanal and postanal myomeres, fin development and pigmentation. Dorr et al. (1976) described characteristics of trout-perch larvae collected in Lake Michigan.

Table C16. Continued.

Dorr, J. A., III, D. J. Jude, F. J. Tesar and N. J. Thurber. 1976. Identification of larval fishes taken from the inshore waters of southeastern Lake Michigan near the Donald C. Cook Nuclear Plant, 1973-1975. Pages 61-82 in J. Boreman ed. Great Lakes fish egg and larvae identification: proceedings of a workshop. Nat. Power Plant Team, Off. Biol. Serv., U.S. Fish Wildl. Serv., Ann Arbor, Mich.

Fish, M. P. 1929. Contributions to the early life histories of Lake Erie fishes. Bull. Buffalo Soc. Nat. Sci. 14:136-187.

______. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary water. Bull. U.S. Bur. Fish. 47:293-398.

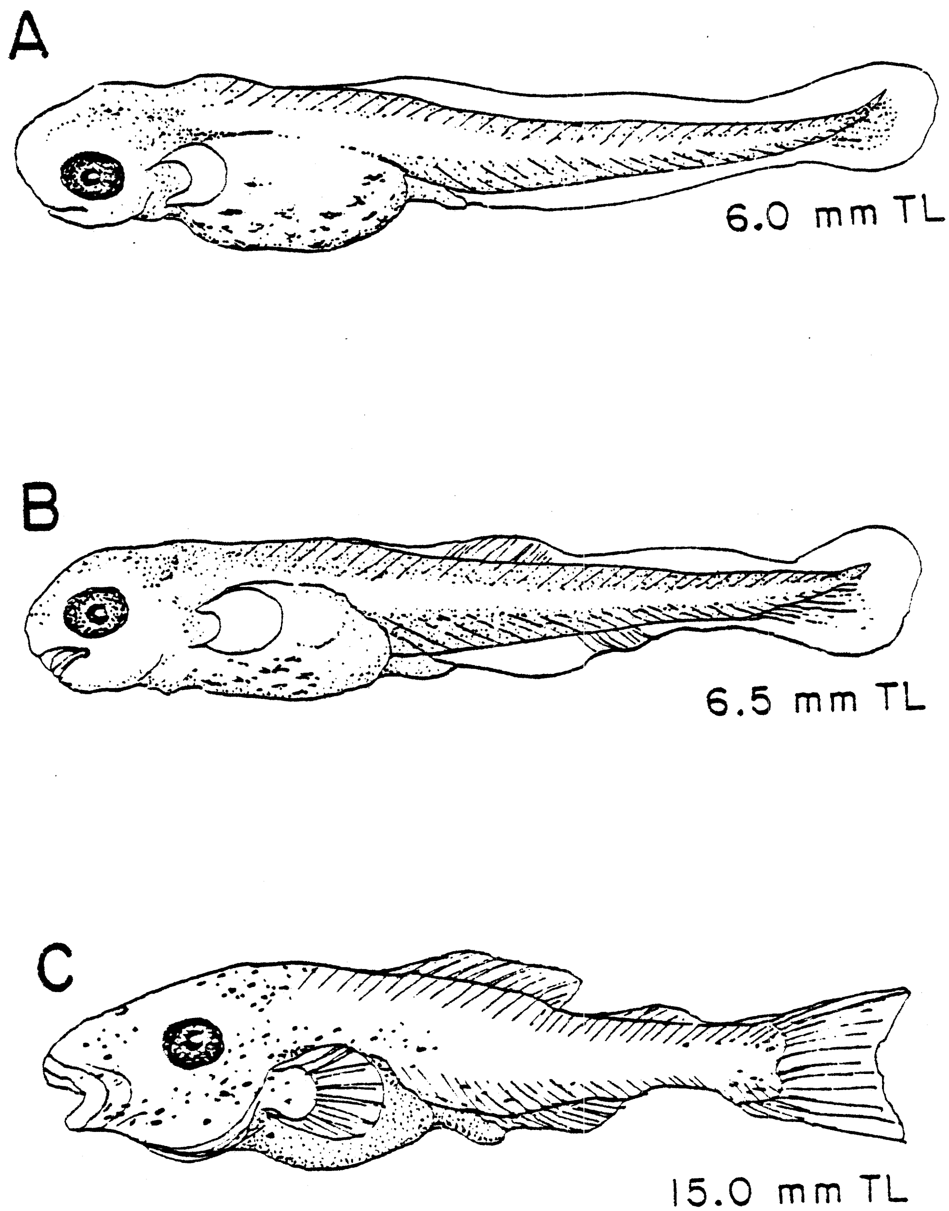

Fig. C31. Generalized illustration of the larvae of the trout-perch, Percopsis omiscomaycus. (A) protolarva, (B) mesolarva, (C) metalarva. Drawings were made from larvae collected in Lake Michigan during 1973-1979.

TABLE C17. Some identifying characteristics of johnny darter (*Etheostoma nigrum*) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1974-1979. See Fig. C32 for illustrations.

Early stages of larval development

1) Approximate length at hatching: 5.0 mm TL.

2) Myomere count: preanal 17; postanal 25.

3) Postanal length enters preanal length about one time.

4) Mouth: becomes small, inferior and slightly oblique by late larval stages.

Gut: yolk sac entire, oil globule present.

Body: slender. Head small, snout protruding.

Fins: pectoral fins rayed by 10.3 mm TL.

5) Pigmentation: numerous small round melanophores on dorsal aspect of head. A few elongate melanophores on ventral aspect of larva between vent and base of caudal fin.

Late stages of larval development/early juvenile stage

1) Head, position of pectoral fins and body form distinctly recognizable as "darter" in shape by 10.0 mm TL.

Synopsis and selected references

The following selected references were useful in identification of johnny darter larvae. Fish (1929, 1930, 1932) described and included drawings of johnny darter (5-35 mm) collected in Lake Erie. Fish studied larval development from embryonic through adult stages and briefly discussed spawning. Key identification characteristics used were: total length, length to vent, body depth, eye diameter, total preanal and postanal myomeres, fin development and pigmentation. Dorr et al. (1976) described characteristics of johnny darter larvae collected in Lake Michigan.

Dorr, J. A. III, D. J. Jude, F. J. Tesar and N. J. Thurber. 1976. Identification of larval fishes taken from the inshore waters of southeastern Lake Michigan near Donald C. Cook Nuclear Plant, 1973-1975. Pages 61-82 *in* J. Boreman, ed. Great Lakes fish egg and larvae identification: proceedings of a workshop. Nat. Power Plant Team, Off. Biol. Serv., U.S. Fish Wildl. Serv. Ann Arbor, Mich.

Table C17. Continued.

Fish, M. P. 1929. Contributions to the early life histories of Lake Erie Fishes. Bull. Buffalo Soc. Nat. Sci. 14:136-187.

______. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. Bull. U.S. Bur. Fish. 47:293-398.

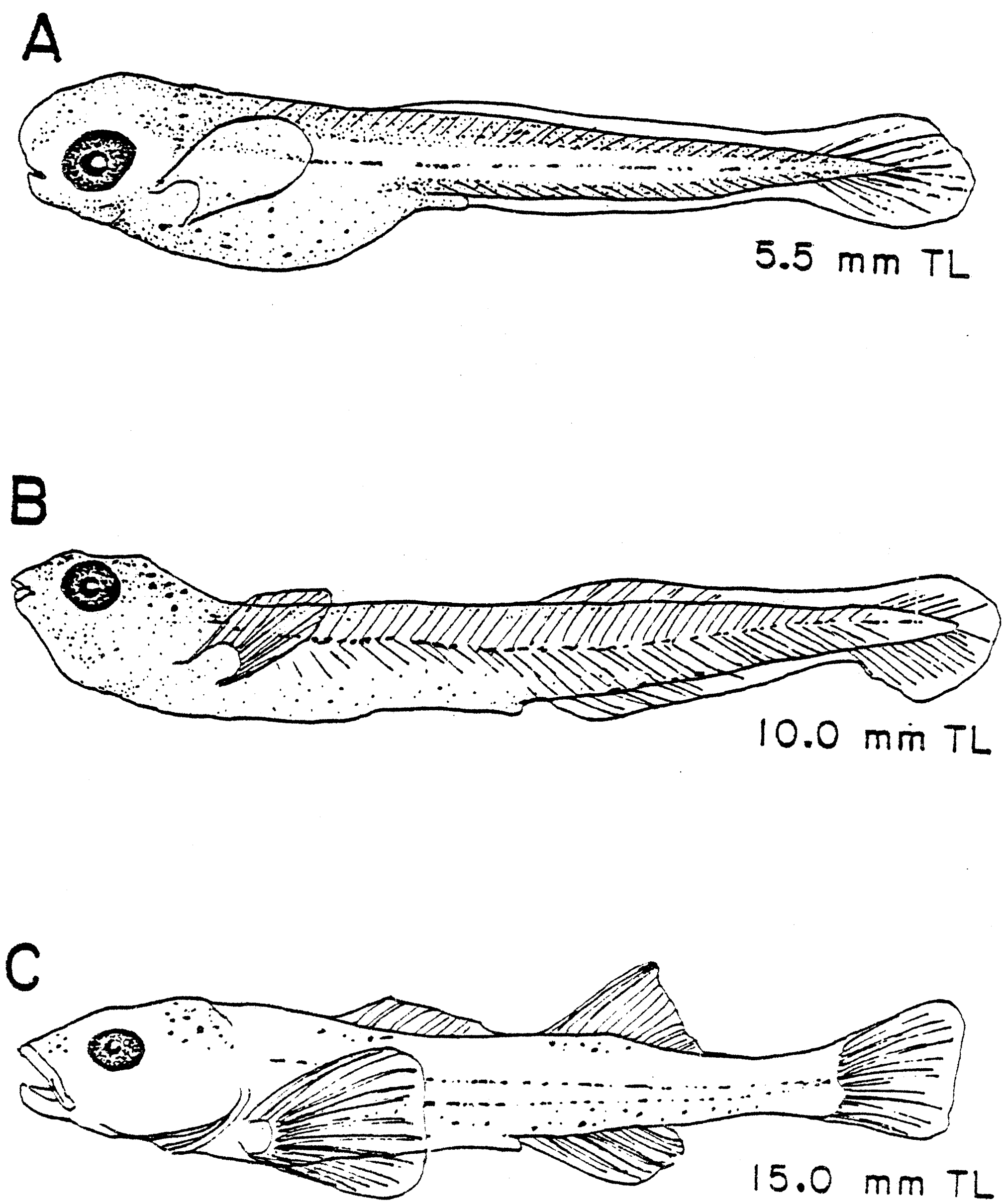

Fig. C32. Generalized illustration of the larvae of the johnny darter, *Etheostoma nigrum*. (A) protolarvae, (B) mesolarva, (C) metalarva. Drawings of proto- and mesolarvae were made from larvae collected in Lake Michigan during 1973-1979. Metalarva modified from Fish (1929).

TABLE C18. Some identifying characteristics of yellow perch (*Perca flavescens*) larvae compiled from literature (see selected references) and from analysis of specimens collected from the inshore waters of southeastern Lake Michigan, 1973-1979 and the western basin of Lake Erie, 1975. See Fig. C33 for illustration.

Early stages of larval development

1) Approximate length at hatching: 5.0 mm TL.

2) Myomere count: preanal 16-18 (range in literature 16-24); postanal 19-21 (range in literature 16-21).

3) Postanal length enters preanal length approximately one time.

Mouth: readily apparent at hatching, becomes large terminal and slightly oblique by late larval stages. Jaws prominent and well developed early in larval development.

Gut: yolk sac not entire and containing a large anterior oil globule. Vent very prominent and strongly decurved.

Body: robust. Head large and triangular, snout blunt.

Fins: pectoral fins moderately well developed at hatching, becoming large and rayed early in larval development.

Other: yolk sac absorbed by 8 mm TL.

5) Pigmentation: a few small, round melanophores on lateral aspects of larva (often concentrated along myosepta). A few small, stellate melanophores near vent.

Late stages of larval development/early juvenile stage

1) Base of anal fin relatively short. Anal spines 2, anal rays 6-8.

Synopsis and selected references

The following selected references were useful in identification of yellow perch larvae. Browne (1909) discussed spawning, egg development, hatching and immediate post-hatching characteristics of yellow perch and provided a drawing of a prolarval yellow perch. Ryder (1885) described yellow perch spawning and prolarval characteristics; figures depicting egg development were also included. Fish (1929) examined yellow perch eggs, larvae and adults captured from Lakes Nipigon, Ontario and Erie. She described spawning, egg development, prolarval and postlarval characteristics (drawings of which were included) and the adult stage of

yellow perch. Fish (1932) described developmental stages of yellow perch from embryonic through adult forms and supplied illustrations of larvae from 5.6 to 20.5 mm. Norden (1961) collected and studied larval yellow perch and walleye from Lakes Erie and Michigan and concluded that the most important characteristics for distinguishing yellow perch larvae from walleye larvae were: postanal myomere count, yolk sac length, intestinal length, snout-to-anus and anus-to-caudal length, and location of the lower jaw articulation. Pigmentation was described and found to vary considerably between specimens. Descriptions and drawings of prolarvae and postlarvae of yellow perch and walleye were presented along with a list of morphometric and meristic characters. Faber (1963) described yellow perch development at several stages: straight notochord stage (up to 9 mm), caudal fin stage (9-12 mm) and pelvic ray stage (15-18 mm). Key characteristics used to distinguish between various stages were: yolk type, finfold formation, pigmentation, myomeres and fin development. Faber also categorized morphometric changes with regard to specific developmental stages. He stated that all body parts measured showed a linear increase in length with time except straight-intestinal length which decreased during development due to formation of the stomach cavity. Mansueti (1964) studied yellow perch development from egg through adult forms in fish collected from Chesapeake Bay. She presented detailed written descriptions and illustrations of the various developmental stages (5.5-30 mm) of yellow perch. Morphometric relationships, such as head length and snout-to-vent length, increased at a rate proportional to changes in total length. Lippson and Moran (1974) described spawning, egg characteristics and development of larvae through adult yellow perch, based on studies conducted in the Potomac River Estuary. Drawings of various developmental stages of yellow perch are included in this identification manual. Hogue (1976) described yellow perch larvae collected from the Tennessee River Valley. Dorr et al. described characteristics and relative abundance of yellow perch larvae collected in Lake Michigan.

Browne, F. B. 1909. On the early stages in the life histories of certain fresh-water fishes. Trans. Norfolk Norwich Natural. Soc. 8:478-488.

Dorr, J. A., III, D. J. Jude, F. J. Tesar and N. J. Thurber. 1976. Identification of larval fishes taken from the inshore waters of southeastern Lake Michigan near Donald C. Cook Nuclear Plant, 1973-1975. Pages 61-82 _in_ J. Boreman ed. Great Lakes fish egg and larvae identification: proceedings of a workshop. Nat. Power Plant Team, Off. Biol. Serv., U.S. Fish. Wildl. Serv., Ann Arbor, Mich.

Faber, D. 1963. Larval fish from the pelagic region of two Wisconsin Lakes. Ph.D. Thesis. Univ. Wis., Madison Wis. 122 pp.

Table C18. Continued.

Fish, M. P. 1929. Contributions to the early life histories of Lake Erie fishes. Bull. Buffalo Soc. Nat. Sci. 14:136-187.

______. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. Bull. U.S. Bur. Fish. 47:293-398.

Hogue, J. J., Jr., R. Wallus and L. K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Tech. Note B19. Div. For. Fish. Wildl. Dev. T.V.A. Norris, Tenn. 67 pp.

Lippson, A. J. and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River Estuary. Misc. Pub. No. 13. Environ. Tech. Cent., Martin Marietta Corp., Baltimore, Md. 282 pp.

Mansueti, A. J. 1964. Early development of the yellow perch, Perca flavescens. Chesapeake Sci. 5:46-66.

Nordon, C. R. 1961. The identification of larval yellow perch, Perca flavescens and walleye, Stizostedion vitreum. Copeia 1961:282-288.

Nordqvist, H. 1914. Bidrag till kennedomen om vara sotvattensfiskars larvstakier. Arkiv for Zoologi 9(4):1-49. (Figs. 19, 20, 21).

Ryder, J. A. 1887. Development of osseous fishes, including marine and freshwater forms. U.S. Comm. Fish. Rep. 13(1885):489-604. (30 pls).

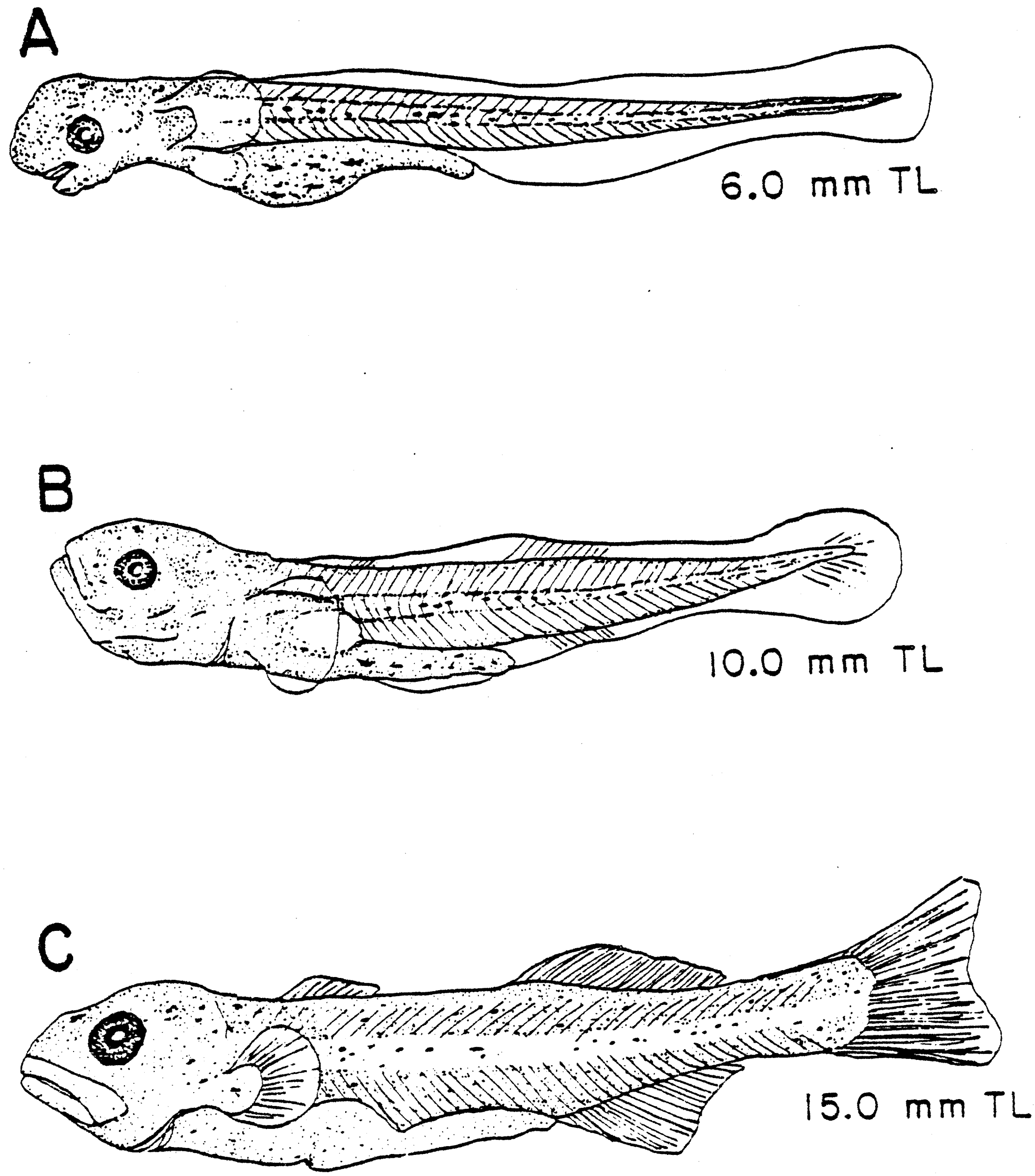

Fig. C33. Generalized illustration of the larvae of the yellow perch, Perca flavescens. (A) protolarva, (B) mesolarva, (C) metalarva. Drawings of protolarva were made from larvae collected in Lake Michigan during 1973-1979. Meso and metalarvae drawings were made from Lake Erie specimens.

SECTION D

ENTRAINMENT OF FISH LARVAE AND EGGS DURING 1973-1974 AT THE D.C. COOK NUCLEAR PLANT, SOUTHEASTERN LAKE MICHIGAN, WITH RECOMMENDATIONS ON SAMPLING

INTRODUCTION

The effect of condenser passage on the larvae and eggs of Lake Michigan fishes is one of the potentially serious consequences of using Lake Michigan water for once-through cooling. We have therefore devoted considerable effort to devising a sampling design and apparatus that will document species, numbers and sizes of larvae and eggs passing through the Cook Plant. Since 1974 was a preoperational year (on-line status of Unit 1 occurred January 1975), entrainment collections were sporadic because of ongoing construction and inconsistent running and testing of Cook Plant circulating water pumps. During most sample collections in 1974, three circulating water pumps (maximum number for Unit 1 operation) were running. At times fewer pumps were operated.

In this section we have presented the 1973-1974 entrainment data, as well as field fish larvae data in summarized form, so statements and predictions about what sizes and species of larvae present in the plant vicinity can be made in reference to entrainment results. Since we feel that larval fish entrainment, and to a lesser degree adult and juvenile fish impingement, are the two most deleterious effects the plant has on fish populations, it is important to know first what species, sizes and numbers of larvae are entrained; second, how abundant these larvae are in the field so losses can be viewed in perspective and third, exactly where various sizes and species of larvae are located, so that future plants sited on Lake Michigan may benefit from these findings.

Understanding entrainment losses must first start with a general comprehension of adult fish spawning behavior in the vicinity of the Cook plant. Most Lake Michigan fishes have a similar seasonal pattern of movements. They come inshore during spring and early summer for spawning and feeding, remain there during summer and leave in the fall for deeper water. Salmon, trout and coregonids differ in that they are usually present inshore during spring, fall and upwellings in summer. Thus entrainment of larval fish will peak during times of heaviest hatching and will be negligible or sporadic thereafter. The effects of one power plant on such an immense biological system like Lake Michigan are expected to be small, but effects of several plants operating at once must be evaluated on a lakewide basis.

METHODS

The Cook Plant is a two-unit, 2,200 megawatt nuclear plant located on the shore of southeastern Lake Michigan near Bridgman, Michigan. Intake

structures (3) and discharge structures (2) are located 686 m (2,250 ft) and 366 m (1,200 ft) respectively offshore (Fig. D1); intakes are in 7.3 m of water based on a mean lake level of 579 ft above sea level, and discharges are in 5.5 m of water (U.S. Atomic Energy Commission 1973). The plant's intake pipelines are laid beneath the sand bottom. Riprap material from which the intake structures emerge is built up 2.1 m above the bottom. The intake structure itself protrudes another 2.5 m above that. Therefore, most intake water which enters the plant is drawn from the 3-5-m strata in the 7.3-m deep water column. Intake velocity is about 0.4 m/s (1.3 f/s), which increases to 1.8 m/s (6 f/s) within the intake pipes. Total cooling-water transit time from intake to discharge is about 10 min; cooling-water transit time through the steam condensers is about 6 s. Water is discharged through slot-type jet diffusers at about 4 m/s (13 f/s). When both units are on-line 104 m^3/s (1.6 million gal/min) will be used for once-through cooling. The predicted delta T for Unit 1 is 12.1 C (21.8 F) while for Unit 2 it is 9.3 C (16.7 F). During normal operation of Unit 1, almost 4 million m^3 of water passes through the plant every 24 h.

Entrainment Sampling

Two kinds of entrainment sampling were performed -- seasonal sampling to monitor kinds and number of larvae and eggs entrained, and supplementary sampling to test statistically the horizontal and vertical stratification of larvae and eggs in the forebay. The latter study was done in 1975 and will only be mentioned when it is pertinent to 1974 results and choice of a sampling location in the intake forebay. An entrainment sampling unit (Fig. D1A) consisted of a 300-liter/min (80 gal/min) Hale diaphragm pump (actual capacity varied, but averaged 208 liter/min) with a 7.6-cm (3 in) diameter hose extending from it into the intake forebay (maximum depth was 10.1 m). Sampling was done at 2, 5 and 9 m, but mostly at 5 m. For all sampling, water was pumped into a 0.5-m diameter, no. 2 nylon, 363-micron mesh plankton net suspended into a 208-liter (55 gal) drum. Volume of water filtered through the net was measured with a flowmeter connected to an effluent pipe extending from the drum. All samples were preserved in approximately 10% formaldehyde. Fish larvae (defined as any fish 25.4 mm or less in total length) and fish eggs were removed from samples with the aid of a binocular microscope and a lighted sorting chamber (Dorr 1974a). Larvae were measured to the nearest 0.1 mm (total length). Larvae counts were converted to number per 1000 m^3 by calculation based on volume filtered.

For seasonal entrainment sampling two pumping units were located at grate 3 and one at the discharge (Fig. D1B). There are seven grates (about 5 m x 1 m) located in the intake forebay floor which span the entire length of the screenhouse (Fig. D1B). Unit 1 circulation pumps draw water mainly under grates 1, 2 and 3. Samples were collected about every 6 h through grates 2 and 3 during one 24-h period about once per month during 1974, a preoperational year. During 1975, the first year of Unit 1 operation, 24-h sampling was performed twice per month during all months except June, July and August when sampling was done once per week, also for 24 h.

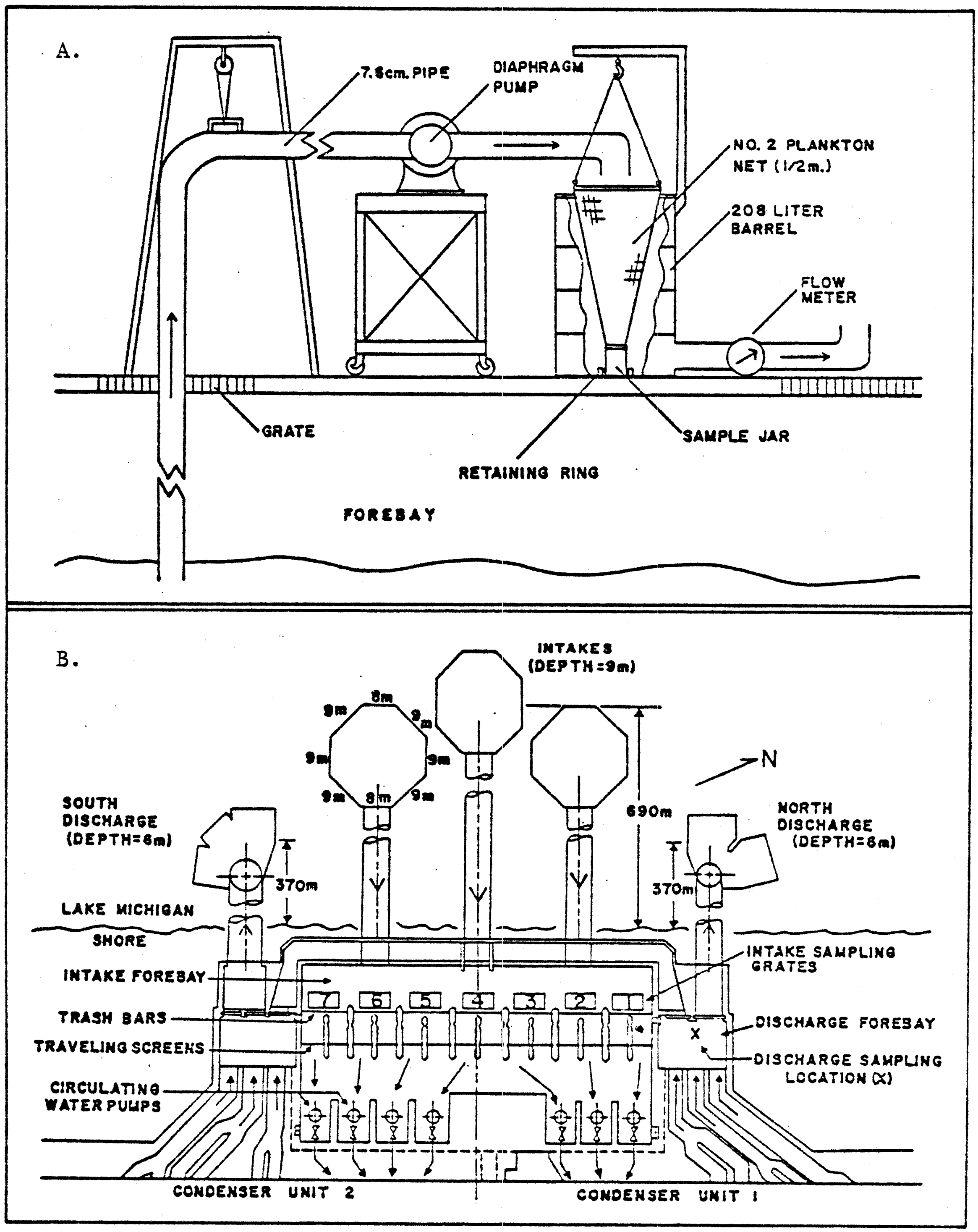

Fig. D1. A.) Schematic diagram of an entrainment sampling unit, showing forebay, sampling pipes, diaphragm pump, plankton net and flowmeter in the discharge pipe. B.) A diagram of the screenhouse and intake-discharge pipes in Lake Michigan. Also shown are the traveling screens, circulating water pumps and intake-discharge forebay grates where entrainment sampling was conducted.

Field Sampling for Fish Larvae

In order to compare field catches of fish larvae in the vicinity of the intake with catches obtained during entrainment sampling, a brief description of our field sampling methods is given. Field sampling for fish larvae was conducted once per month April through November with a no. 2, 0.5-m diameter plankton net towed horizontally at 10 stations around the Cook Plant (see SECTION C). Samples were taken once during the day and once at night at 0, 2, 4 and 6 m at 6-m stations and at 0, 2, 4, 6 and 8 m at 9-m stations. Tows lasted 5 min. A flowmeter (Rigosha) centered in the opening of the net measured volume sampled, which was used to convert numbers of fish larvae and eggs captured to numbers per 1000 m^3. Larvae and eggs were identified using techniques discussed in SECTION C.

RESULTS

Daily Entrainment

Larval fish entrainment at the D. C. Cook Plant reflects the abundance of adult fish which spawn in that area of southeastern Lake Michigan. The five most abundant species in the area are alewife, spottail shiner, rainbow smelt, yellow perch and trout-perch. Detailed survey results on all species can be found in SECTION B. Only eight species of larval fish were collected during 1973-1974 in field and entrainment samples -- alewife, rainbow smelt, spottail shiner, yellow perch, trout-perch, johnny darter, sculpin and ninespine stickleback. Unknown (unidentified) and damaged larvae were also found. In 1975, burbot, fourhorn sculpin and carp larvae were also collected.

Some brief life history notes on major species (see SECTION B for details) will place entrainment results in perspective. Alewives have a prolonged spawning season and larvae were found June through August with late June-early July being months of maximum larvae abundance. We observed alewives spawning during June, usually at night, in the beach zone (2-m depth to shore) and at the 9-m contour. Since alewife eggs are demersal, nonadhesive (Scott and Crossman 1973) and easily stirred up from the bottom due to storms and currents, they are particularly susceptible to entrainment.

Rainbow smelt have a short spawning season of about 2 wk when water temperature reaches about 10 C, usually in late April or May. Their spawning appears to occur mostly at night near the beach or in streams. Smelt eggs have an adhesive stalk which may attach to the substrate and therefore incure reduced potential for entrainment because they are non-pelagic.

Most yellow perch spawning also occurs over a short time span (about 2 wk) in late May and early June. They do not appear to spawn extensively in the Cook Plant area and since their eggs are laid in long gelatinous strings on or around objects, it is expected egg entrainment losses would be

slight. Spottail shiners spawn during June and July and their eggs are adhesive. Spottail spawning does occur in the Cook Plant area, since eggs collected by our SCUBA divers (Dorr and Miller 1975) from the intake structures were reared and identified as spottail shiners. Trout-perch spawn from May through September; little is known about their larvae, eggs or spawning attempts in the Cook Plant vicinity. We believe they, like yellow perch, spawn elsewhere or occur in such low numbers that few are sampled.

In 1974, 96 entrainment samples (93 from the intake, 3 from the discharge) representing 1242 m^3 of water filtered were collected in May, July, August and November. Amount of water sampled during all 1974 entrainment collections (1242 m^3) represented about half the water pumped through the plant in 1 min at typical Unit 1 operation, which was 2688 m^3/min. This amply demonstrates sampling design considerations one must cope with when trying to accurately assess larval concentrations in such large volumes of water. In the samples collected, 126 larvae and 493 fish eggs were found.

In May, an estimated 46,000-177,000 smelt larvae were entrained daily into the Cook Plant's condenser system (Table D1). Fewer smelt eggs (5,000-36,000) were entrained.

On 23 July 1974, an estimated 1.4 million alewife larvae and 19.6 million alewife eggs passed through the plant in 24 h. The next day less than 1 million eggs and larvae were estimated to pass through the plant, indicating the large day-to-day variation in entrainment of larvae that can occur.

During July-August 1975, some spottail shiners (6,000-89,000) and undetermined larvae (64,000-203,000) were entrained per 24 h, while during July 1974, only alewife were found in samples. This species difference was probably due to more extensive sampling during 1975. In August 1974, large numbers of alewives (up to 2.5 million), spottails (150,000), trout-perch (77,000) and some undetermined larval fish (77,000) were entrained during a 24 h period. Between 1.2 and 12.3 million alewife eggs also passed through the plant on a daily basis in August.

By November 1974, few larvae of any species were present, as most had grown to a large size and apparently migrated to deeper water. However, a few alewives, spottails and trout-perch were found in samples leading to estimated daily entrainment abundances in November of 9, 5 and 10 thousand, respectively.

Number and Length of Entrained vs. Field-Caught Larvae

A comparison of the abundance and size of fish larvae caught in the intake forebay with those caught in Lake Michigan in the field monitoring program gave valuable information about which species and sizes were susceptible to entrainment. These comparisons were also useful in verifying

Table D1 . Number of fish larvae entrained, circulation pump volumes, amount of water sampled and daily (24 hr) estimates of entrainment losses assuming 100% mortality at the Cook Nuclear Plant, southeastern Lake Michigan, 1974. (AL = alewife; SM = smelt; SP = spottail shiner; TP = trout-perch; XX = unknown larvae; EG = fish eggs).

Date	Plant Circulation Pumps Vol./24 hrs (m^3)	Plant Circulation Pumps flow rate m^3/min	Volume Water Sampled/24 hrs (m^3)	Forebay location	No. larvae & eggs captured	No. larvae & eggs/1000 m^3 [1]	Daily estimates of entrained larvae & eggs
1974							
7 May	1,307,520	908	111.68	intake	15 SM	130 SM	170,000 SM
					1 EG	9 EG	12,000 EG
			108.65	discharge	15 SM	140 SM	180,000 SM
					3 EG	28 EG	37,000 EG
8 May	1,288,800	895	269.95	intake	18 SM	67 SM	86,000 SM
					1 EG	4 EG	4,100 EG
			195.53	discharge	7 SM	36 SM	46,000 SM
					3 EG	15 EG	19,000 EG
23 Jul	4,445,280	3,087	67.04	intake	22 AL	310 AL	1,400,000 AL
					300 EG	4,400 EG	20,000,000 EG
24 Jul	4,445,280	3,087	9.61	intake	2 AL	200 AL	920,000 AL
					2 EG	200 EG	920,000 EG
6 Aug	4,559,040	3,166	60.26	intake	33 AL	550 AL	2,500,000 AL
					2 SP	33 SP	150,000 SP
					1 TP	17 TP	78,000 TP
					1 XX	17 XX	78,000 XX
					160 EG	2,700 EG	12,000,000 EG
7 Aug	4,420,800	3,070	62.77	intake	7 AL	110 AL	500,000 AL
					18 EG	290 EG	1,300,000 EG
20 Nov	1,296,000	900	136.15	intake	1 AL	7 AL	9,100 AL
					1 TP	8 TP	10,000 TP
21 Nov	1,313,280	912	220.84	intake	1 SP	4 SP	5,300 SP
					6 EG	27 EG	35,000 EG

[1] Weighted averages were used.

whether our pumping methods were adequately sampling the local Lake Michigan larval fish populations that were being entrained.

Because of patchy distribution of fish larvae in the field, an average of a large number of field samples should more closely approximate concentrations found in the intake forebay than would a single or group of observations taken, for example, from near the intakes. Thus, mean number of field-caught larvae per 1000 m^3 were calculated for 1973-1974 for selected months by day, night and both combined (Table D2). Averaging was done combining depths (four or five depending on station), stations (two -- 6 and 9 m) and areas (Cook and Warren Dunes). There was good agreement between the mean concentrations of May 1974 field-caught smelt larvae and intake forebay entrainment concentrations on 7-8 May 1974. Fewer field-caught smelt were captured during the day than at night, which was attributed to a suspected diel vertical migration by smelt upward at night (with accompanying increase in activity) and downward during the day (with a decrease in activity). Entrainment samples reflected this trend, since day catches were lower than comparable night catches. In general, concentrations of smelt in entrainment samples were consistently a little less than field sample concentrations.

In 1974 July and August seasonal entrainment samples, only alewives were captured. A ten-fold difference between July field-sample concentrations of larvae (2404/1000 m^3) and July entrainment-sample concentrations (316/1000 m^3) was probably the result of time disparity (13 days) between sampling dates (Table D2). For all 6- and 9-m field samples (June-August), more alewives were caught at night than during the day, which was undoubtedly due to daytime plankton net avoidance. More alewives were caught at night in August entrainment samples, but not in July samples. Final determination of this disparity must await further data.

In early July 1974, spottail shiners and yellow perch were present in some field samples, but were not entrained. Volume filtered during entrainment sampling was low (76 m^3), but it is known (see SECTION C) that spottail shiner larvae were mostly distributed demersally inshore (3 m to shore), while yellow perch were found consistently in the upper strata of water at 6- and 9-m stations. Thus, these two species should be less susceptible to entrainment. Some spottail shiners, however, were captured during the 1975 depth-grate studies, indicating that some do stray from the inshore zone. Although no larvae were caught during field sampling in November 1974, a few alewives, trout-perch and some unidentified larvae were entrained. Concentrations, however, were very low (Table D2). It is clear that entrainment and field sampling times should coincide so that water movements, growth and change in behavior of larvae and hatching of new larvae do not affect distribution and susceptibility to capture during intervening days.

Length-frequency distributions of rainbow smelt entrained in May 1974 (Fig. D2 -- and uncombined data) showed that larvae of the same length (modal size at 4.6-5.0 mm) were entrained both day and night; thus, no

Table D2. A comparison of mean field concentrations (#/1000 m^3) of fish larvae with mean concentrations derived from entrainment studies. Field data were collected in the Cook Plant vicinity during 1973-74; entrainment data are from 1974. Number of samples and volume filtered refers to the combined (24 hr) data. Numbers in parenthesis are standard deviations. Concentrations at the intake level were taken from the 6 m tow at the 9 m Cook station.

					In Lake Michigan or Cook Forebays				At Intake Level (6 m)			
Date	No. of samples	Type of sample	Volume filtered (m^3)		Alewife	Smelt	Yellow perch	Spottail shiner	Alewife	Smelt	Yellow perch	Spottail shiner
26-28 Apr 1973	32	Field	426	Day:	0	0	0	0	0	0	0	0
				Night:	0	270(320)	0	0	0	140	0	0
				Comb:	0	130(260)	0	0	0	71	0	0
13-14 May 1974	36	Field	690	Day:	0	100(97)	0	0	0	190	0	0
				Night:	0	220(220)	0	0	0	200	0	0
				Comb:	0	160(180)	0	0	0	190	0	0
7-8 May 1974	25	Entrainment-intake	377	Day:	0	46(130)	0	0	-	-	-	-
				Night:	0	180(280)	0	0	-	-	-	-
				Comb:	0	120(230)	0	0	-	-	-	-
	3	Entrainment-discharge	304	Day:	0	36(37)	0	0	-	-	-	-
				Night:	0	140(0)	0	0	-	-	-	-
				Comb:	0	69(63)	0	0	-	-	-	-
18-19 Jun 1973	32	Field	426	Day:	1800(2700)	0	29(80)	0	150	0	0	0
				Night:	2900(2200)	0	19(44)	33(72)	650	0	0	210
				Comb:	2400(2500)	0	24(64)	16(53)	420	0	0	110
11-12 Jun 1974	36	Field	658	Day:	950(810)	0	47(57)	0	30	0	57	0
				Night:	3900(1800)	0	160(250)	30(98)	5600	0	0	0
				Comb:	2400(2000)	0	110(200)	15(70)	2800	0	28	0
16-17 Jul 1973	32	Field	473	Day:	370(380)	0	0	0	610	0	0	0
				Night:	900(350)	0	0	0	350	0	0	0
				Comb:	640(700)	0	0	0	480	0	0	0
8-9 Jul 1974	36	Field	276	Day:	1800(2300)	0	0	0	330	0	0	0
				Night:	3000(3100)	0	21(69)	270(690)	400	0	0	1600
				Comb:	2400(2800)	0	11(49)	71(280)	390	0	0	300
23-24 Jul 1974	24	Entrainment-intake	77	Day:	430(490)	0	0	0	-	-	-	-
				Night:	200(190)	0	0	0	-	-	-	-
				Comb:	320(380)	0	0	0	-	-	-	-
21-22 Aug 1973	32	Field	382	Day:	12(15)	0	0	0	0	0	0	0
				Night:	72(160)	0	0	0	0	0	0	0
				Comb:	42(120)	0	0	0	0	0	0	0
19-20 Aug 1974[1]	36	Field	679	Day:	120(190)	0	0	0	38	0	0	0
				Night:	330(400)	0	0	0	0	0	0	0
				Comb:	230(330)	0	0	0	19	0	0	0
7-8 Aug 1974	36	Entrainment-intake	123	Day:	110(180)	0	0	0	-	-	-	-
				Night:	560(480)	0	0	32(93)	-	-	-	-
				Comb:	330(420)	0	0	16(66)	-	-	-	-
10 Nov 1974	18	Field	232	Day:	0	0	0	0	0	0	0	0
				Night:	0	0	0	0	0	0	0	0
				Comb:	0	0	0	0	0	0	0	0
20-21 Nov 1974	6	Entrainment-intake	357	Day:	9(15)	0	0	0	-	-	-	-
				Night:	0	0	0	5(8)	-	-	-	-
				Comb:	4(11)	0	0	2(6)	-	-	-	-

[1] Trout-perch and unknown larvae excluded if present.

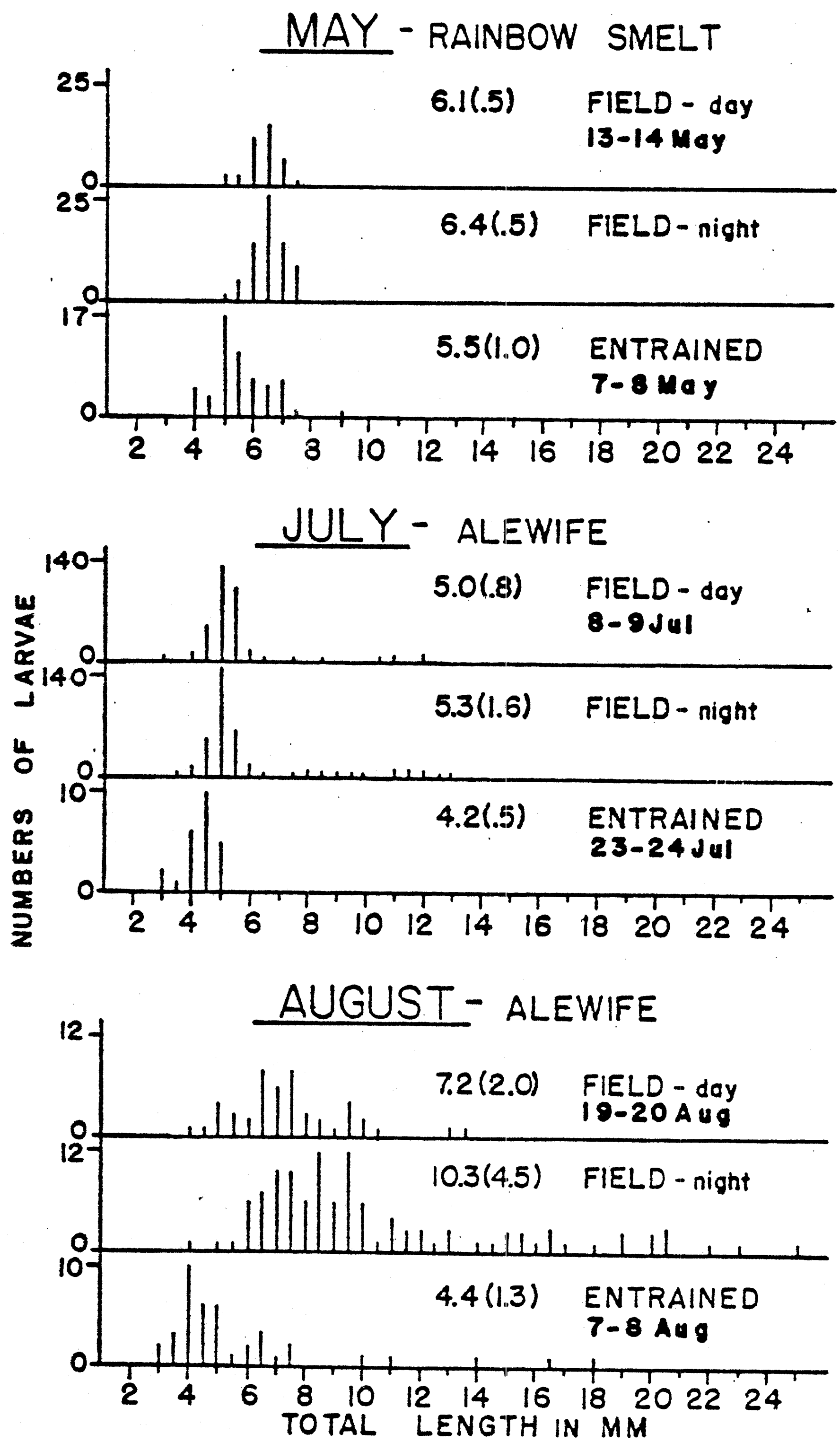

Fig. D2. A comparison of the total lengths of field-caught fish larvae with those entrained during the same months 1974 at the Cook Plant, southeastern Lake Michigan. Day and night samples were separated for field samples, while entrainment samples were pooled. Mean length and, in parentheses, standard deviation are also given.

differential sampling of size groups related to diel changes in physical conditions (e.g., light) occurred in the intake forebay. The closely-grouped, unimodal length-frequency histogram also demonstrated the type of pattern expected for a species which spawns over a short time period. May entrainment samples compared with field samples collected 4 days later (Fig. D2) showed that the modal size of field-caught smelt larvae had increased through normal growth in the intervening days by about 1.5 mm from 4.6-5.0 mm on 7-8 May to 6.1-6.5 mm on 13-14 May. We concluded that the forebay pumping methods were adequately sampling the size groups of smelt in the lake.

A comparison of the length-frequencies of entrained and field-caught alewife larvae for July was confounded by the discrepancy in time between sampling dates, 13 days. A large size-range of alewives (3-13 mm) was observed in July field samples (Fig. D2); only larvae 5 mm or less were collected during July entrainment sampling. Larvae 5 mm or less are newly hatched, probably planktonic and thus have very little ability to avoid intakes or our forebay sampling pumps. Thus, it appeared that during July, forebay sampling was only collecting the most recently hatched larvae and that larger fish larvae were either not entering the intakes or avoiding the sampling pump.

Results for August (Fig. D2) were somewhat contrary to those of July, since similar sizes of alewives were collected in both field and entrainment samples. Sampling again occurred 12 days apart. A greater proportion of entrained alewives, however, were newly hatched fish 3-5-mm long, as was found with the July entrainment results; and the largest alewife entrained was 18 mm, while 25-mm larvae were observed in field samples.

DISCUSSION

Conducting the Sampling

The execution of even a modest sampling scheme requires an enormous investment in people, equipment and time. Most pumps are expensive; diaphragm pumps even more so than centrifugal. Diaphragm pumps were used because we felt they would damage larvae less than centrifugal pumps. This assumption appears unjustified, since larvae often were severely damaged when removed from sample jars. However, we believe this may be due to the abrasive effects of sand on the larvae while they are in the net. Time, effort and experimenting were required to perfect the most efficient deployment of equipment for suspending pumps and hoses. We believe that sampling with a plankon net for assessing entrainment effects would be more accurate, efficient and less costly, but physical limitations of the Cook Plant forebays and discharge pipes prevented their use.

Forebay Sampling Location

Sampling was conducted at three depths and one grate in the intake forebay during 1974. A preliminary experiment was conducted in 1974 at

those depths (2, 5 and 9 m) to establish whether stratification of larvae and eggs occurred. This study failed because the 15 min sampling time used was too brief to collect adequate numbers of larvae for sufficient statistical testing. These studies were improved, redesigned so that a 4 h unit of time was used, and conducted during 1975. Detailed discussion of this experiment can be found in Jude (1976). Briefly, we found no significant differences at the 0.05 level among the three depths (2, 5 and 9 m) and three grates (2, 5, 7) in the concentrations of total larvae, alewife larvae and fish eggs. Variability in data was great. However, based on these results, we chose grate 3 and the 5-m depth and placed three pumps there to do all of our seasonal monitoring in the intake forebay. Since the discharge forebay is sealed and water there highly mixed, we placed one sampling pipe at 5 m and performed no statistical studies to verify the assumptions inherent in the decision.

Sampling Problems

Extrapolating the few larvae collected to the total number traveling through the plant is a risky calculation at best. With present water volumes filtered, we sample about .0002% of the total cooling-water flow. Even increasing our sampling by a factor of 10 would not change that number significantly. Present plants are only accidently designed so that adequate sampling can be carried out in forebays. Safety of plant operating personnel takes precedence over access to forebays, and finding means to sample demands ingenuity. A solution of the sampling problem at one plant seldom can be carried over to another plant. Our attempts to suspend large nets in the Cook Plant forebay were thwarted by poor accessibility and water velocities too low to keep such nets in sampling posture. The criteria for sampling should be based on gathering enough samples so that reliable statistical tests and calculations can be made with a good measure of variation (i.e., standard deviation) associated with each series of samples.

Data Variability

Numbers of larvae captured in a given set of samples were highly variable due to patchy distribution of larvae in Lake Michigan, unknown changes in their distribution in the Cook plant forebays, diel variations in activity of larvae and water movements in the lake (particularly upwellings) due to weather. Unknown differential gear susceptibility of different size larvae also contributed to variance in data. Such variability leads to statistical analysis problems. Too many zero data points lead to skewed data and possibly non-normality of the data set. High variances can lead to inconclusive results. Number of larvae captured was a discrete variable, but when multiplied to convert to no./1000 m^3 it was turned into a pseudo-continuous variable.

Larval and Egg Mortality and Susceptibility to Entrainment

At present we assume 100% mortality of entrained larvae because we believe the effort required to get meaningful data was not justified due to

problems inherent in doing mortality studies at the Cook Plant. The Cook Plant has an offshore discharge located in 6 m of water which utilizes jet diffusers to rapidly cool heated effluent. It is almost impossible to get a sample of larvae in the discharge plume area that is not mixed with unheated Lake Michigan water. Therefore the method of Marcy (1971) would be difficult and dangerous (unstable boat over the disturbed discharge area) to implement. Pumps we use for sampling simply do not capture enough larvae in a short enough period to perform good live-dead counts, and considerable pump-induced and net-impingement mortality probably would occur.

Fish eggs entrained at Cook are mostly those of alewife and some smelt. We feel little heat-induced damage is done to alewife eggs because Schubel (1975) has shown no effects on hatching success of alewife eggs under thermal exposures (delta T = 10 C for 3 min) similar to those at Cook. Variable sensitivity of different developmental stages of eggs and effects of mechanical and pressure changes and chlorination still must be evaluated. In addition, we have found many eggs that were entirely covered with fungus and probably dead before they were entrained. We do not distinguish between live and dead eggs even if it were possible, so estimates of number of live eggs entrained are biased upward by inclusion of already dead and unfertilized eggs in counts. Also, eggs may be derived from adult fish in the forebay.

More information on larval natural mortality and differential vulnerability of sizes and species of larvae to entrainment is necessary to interpret entrainment losses. Workers at Michigan State University (R. Cole, personal communication, Department of Fisheries and Wildlife) are working on the day-night distributions and natural mortality of larvae in Lake Erie near the Monroe power plant. They have speculated that weakened or dead larvae may drift near the surface during the day and night. It should be noted that Marcy (1971) found that dead larvae sank in the discharge canal of the Connecticut Yankee Plant on the Connecticut River, Connecticut. Healthier larvae during the day, however, tended to distribute themselves near the bottom in Lake Erie and became more uniformly distributed in the water column at night. Thus, surface tows or oblique tows during the day would tend to give low estimates of total numbers of larvae captured and over-represent dead or weakened larvae. Conversely, similar tows at night would give a more accurate picture of both healthy and weakened larvae, since healthy larvae would be more uniformly distributed at this time. If this is true we would expect to entrain more healthy larvae at night at Cook and the same numbers of dead and weakened larvae during day and night. Our field data for alewife larvae show similar numbers of larvae throughout the water column during day and night, with more and larger fish (attributed to daytime plankton net avoidance) caught at night. Weakened and dead fish may be entrained more often than healthy ones. We have seen evidence of such occurrences in our impingement samples of adult fish (see SECTION E), and many times larvae in our entrainment samples were in poor physical condition. However, degradation of larvae in our case was probably due more to residence in the net with abrasive objects such as sand and to impingement against the net itself than to large numbers of dead or

decomposed larvae being entrained.

Susceptibility to entrainment was low for yellow perch which were distributed mostly in surface waters (see SECTION C). Smelt larvae exhibited a diel vertical migration wherein none were caught during the day in 1973 and many were caught at night (Jude et al. 1975). This same pattern was seen in the entrainment data. Alewife larvae appeared to be evenly distributed throughout the 9-m contour water column, accounting for their abundance in entrainment samples both day and night. Demersal species, like sculpin and trout-perch were seldom found in entrainment samples because they were either uncommon in the area or resided near the bottom away from our sampling hose.

Identification of Fish Larvae and Eggs

Larvae and egg taxonomy problems have centered on identifying cyprinids, certain sizes of alewife and smelt and fish eggs. We have surmounted most of the taxonomic problems associated with fish larvae we collected in this part of Lake Michigan, but rely mostly on presence of spawning adults to give an indication of what species' eggs occur in our samples. Egg sizes and unique identifying characteristics of the egg and egg masses were also used.

Gear Avoidance and Selectivity

The problem of gear selectivity influences the results of any fishery investigation and particularly our field larvae and entrainment monitoring. In the field it was obvious that night tows were collecting more and larger larvae and more very mobile, robust larvae like yellow perch than were comparable day tows. Diaphragm pumps also have an inherent selectivity like nets, wherein a decreasing proportion of the population of larvae was sampled, the larger the larvae grew. However, pump avoidance bias in the forebay should have been constant over day and night for a given size of larvae (unlike nets used in Lake Michigan), since there were no diel changes in light intensity in the forebay. Thus, any diel changes in entrainment rates observed should be directly related to changes in behavior and susceptibility of fish larvae to the intakes in Lake Michigan.

Because of the selectivity of the entrainment pumps and the impingement traveling screens (9.5-mm openings), a large proportion of the fish larvae and YOY entrained may not be representatively sampled. We did not collect large numbers of larvae greater than 15 mm in entrainment samples and the smallest size of impinged fish was about 50 mm. Either low numbers of these sizes of fish were entrained (natural mortality would tend to reduce their numbers as the summer progressed) or net avoidance and extrusion through the traveling screens was occurring.

RECOMMENDATIONS

Where to Sample

If no mortality studies are planned and there are adequate data to show that intake and discharge entrainment samples are not significantly different, there is no reason to sample both forebays, particularly if all that is desired are estimates of daily entrainment losses. In fact, the discharge forebay, where water is certain to be well-mixed, is probably the most favorable spot to sample, provided access is possible. If possible, plankton nets should be used for sampling instead of pumps. Nets are easier to handle, filter larger volumes of water, are much simpler to use, provide good replication, take less time to conduct the sampling and usually have less avoidance by larvae than a pump in a similar situation would have. Care must be exercised to make sure velocities are high enough (at least 0.3 m/s) to prevent net avoidance by any fish larvae which survive entrainment. Since any data analyses and statements about entrainment effects must be based on sound statistical data, more replication (more pumps or nets) is preferred to fewer pumps or nets which sample a larger volume.

Amount of Water to Filter

Recommendations on the amount of water that should be filtered to obtain a representative sample were based on field larvae data (Jude et al. 1975 and SECTION C) which for alewife showed that during times of peak abundance in Lake Michigan this species was present in concentrations of about 1-10 larvae per m^3. Thus, if a sample of 50 larvae was desired for a given period, 50 m^3 should be filtered. During times of low abundance of common larvae and for rare larvae, at least 200 m^3 should be filtered (an 0.19 m^3/min, pump which is 50 gal/min, would take about 18 h to pump that amount). Because of the tremendous variability in the numbers of larvae captured, as much replication as possible is encouraged; for the same reason it is desirable to filter as much water as is feasible.

Concurrent Field Larvae Sampling Program

It is very important to conduct a concurrent field sampling program for fish larvae along with entrainment monitoring, even if it is only one station in the vicinity of the intake depth contour. Such a program can elucidate the biology of common species so that entrainment data can be interpreted in light of the natural behavior, condition and distribution of larvae in the area. Simultaneous field and entrainment sampling is crucial if meaningful comparisons between the two are desired. Such comparisons can indicate if only a certain length group of fish larvae is being entrained and give clues on possible pump avoidance by larger sizes of larvae.

A field sampling program can also establish times and frequency during which entrainment sampling should be performed. Entrainment sampling (24 h), based on our experiences with Lake Michigan species, should be done weekly

during peak abundances of larvae, twice a month during minor hatches and once per month during all months when few to no larvae are expected. These recommendations are based on knowledge of the length of the spawning season for adult fish and known time spans of susceptibility of different species of larvae to sampling techniques. The field larvae monitoring program to be conclusive, should minimally at the start have day and night sampling, sampling at discrete depths so the water level at which the intake draws is represented, sampling in the beach zone as well as the offshore zone, and must collect larvae in such a way as to be quantitatively comparable with entrainment data.

Intake Location

Reduction of entrainment losses can be accomplished as proposed by Marcy (1975) by increasing the delta T and decreasing the amount of water that passes through the plant, since most damage to larvae appears due to mechanical and pressure changes. Another, unfortunately expensive, alternative is location of the intakes further offshore. Our alewife larval data suggest an inverse relationship between concentration of larvae and depth. However, our data cover only 1, 6, 9 and 21 m. Data collected at Cook in 1976 at 3-m depth intervals out to 21 m (unpublished data, Great Lakes Research Division) and from eastern Lake Michigan (Jude et al. 1979) suggest this relationship may not be as clear as originally thought. Alewives appeared to be abundant at all depths above the thermocline. Few were ever collected below this apparent thermal barrier. Disadvantages of placement of intakes in water deeper than 9 m besides higher costs, include possible entrainment and impingement of rare and valuable deepwater fish species, such as bloaters, and the benthic invertebrates *Mysis* and *Pontoporeia*.

A recent advance in preventing fish larvae from being entrained through the use of fine mesh screening (0.5 mm) was discussed by Tomljanovich et al. (1977). A number of problems with the use of such screens for Lake Michigan intakes (*Cladophora*, storms, ice) makes us take a cautious view of this proposal.

SECTION E

IMPINGEMENT OF FISH DURING 1973-1974 AT THE D.C. COOK NUCLEAR PLANT

INTRODUCTION

All fish impinged on the traveling screens at the Cook Plant during 1974 were processed. Data were evaluated in terms of seasonal changes in species composition and abundance, relation to species abundance in the Cook Plant vicinity, selectivity of impingement for size and condition and relation of plant activities to numbers of fish impinged.

As 1974 was a preoperational year, total abundance of each species impinged and seasonal changes in abundance cannot be considered an accurate prediction of impingement during a year of full operation. During most months circulating water pumps were run intermittently; sustained pumping over a period greater than a week occurred only in March, July and August. On 25, 29-30 June surge pumping for testing purposes was conducted. No other pumping was done in June. Though daily impingement catches 1-11 April suggest some circulation of water or at least periodic screen washing, the plant had no record of pumps being run in April.

Number of pumps running at one time varied from one to three with resultant variation in flow rates (Table E1). Volume pumped on any one day

Table E1. Monthly summary of volume pumped and flow rates of circulating water at the Cook Plant in 1974. There was no record of pumping in April or June. Data obtained from plant personnel.

	Total volume		Flow rate (liters/min x 10^3)	
Month	liters x 10^9	(gal x 10^9)	Range	(mean)
Jan	17.9	(1.25)	871	
Feb	0.3	(0.08)	871	
Mar	20.5	(5.41)	1105-1113	(1105)
May	3.2	(0.84)	852-965	(878)
Jul	62.0	(16.39)	1052-3238	(2684)
Aug	65.0	(17.17)	3073-3168	(3111)
Sep	29.9	(7.90)	2668-3100	(2998)
Oct	3.0	(0.80)	992-2952	(1491)
Nov	3.9	(1.03)	889-912	(916)
Dec	1.6	(0.42)	2589-2657	(2623)

of operation ranged from 52.2 million to 4.80 billion liters. Service water pumps were running when circulating water pumps were not; however, maximum flow rate for service pumps is 95,000 liters/min compared with 870,000 liters/min for one circulating pump.

METHODS

Fish impinged on the traveling screens are washed into a trough and then flushed into a collection basket. Plant personnel separate fish from debris, place the fish in a plastic bag, then tag and freeze them. In the laboratory, fish are processed in the same manner as field-caught fish (see METHODS, SECTION B).

As we have no record of when traveling screens were run, it is possible that some fish collected from the trash basket on a given day during periods of irregular pumping were actually impinged the preceding 1 or 2 days and may have entered the intake forebay several weeks earlier. Because of this uncertainty, comparisons of day-night catches were not made, and comparisons of catch to volume pumped were made only during periods when pumps were run for 4 or more consecutive days. Comparisons were made between condition of impinged fish and field-caught fish using analysis of covariance. Linear and curvi-linear regressions were used to test for a relationship between numbers of fish caught and volume of water pumped.

RESULTS AND DISCUSSION

Comparison of Impingement Catches: 1973 vs. 1974

Twenty-three species of fish were impinged on the traveling screens in 1974 including eight species (yellow bullhead, rock bass, bluegill, green sunfish, longnose sucker, fathead minnow, quillback and coho salmon) which were not impinged in 1973. Black crappie, bowfin, northern pike and white sucker were collected from the screens in 1973 but not in 1974. It should be pointed out that only limited pumping occurred in 1973 during January-April and October-December, so it is not really possible to compare 1973 with 1974 in terms of species or number of fish collected.

In 1974, 14,848 fish were taken from the screens (Table E2). Five species comprised 99% of the catch: alewife, slimy sculpin, yellow perch, smelt and trout-perch. Alewife alone accounted for 85.5% of the total. Considerably fewer fish were impinged in 1973 when 601 fish were collected (Table E3) comprised of: 43% yellow perch, 24% slimy sculpin, 10% smelt, 10% spottail shiner, 6% alewife and 2% black bullhead. These annual differences in numbers and species composition can be explained by infrequency of pumping in 1973 and because most pumping occurred during winter months, which considerably biased 1973 data.

The total impingement catch for 1974 weighed 432 kg (952 lb) (Table E4); 98.2% were alewives, yellow perch and slimy sculpins. Each remaining

Table E2. Number and species of fish impinged on the Cook Plant traveling screens during 1974.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	% of Total
Alewife	3	1	1854	161	49	5	4335	5429	354	5	119	373	12688	85.4
Spottail shiner	16	2	25	9	4		22	29	7	3	1	9	127	0.9
Rainbow smelt	11		51	35	22	2	52	59	10	1	8	3	254	1.7
Yellow perch	93	11	44	10	63	9	22	89	19	8	19	258	645	4.3
Trout-perch	1		6	4			59	65	28		1	2	166	1.1
Johnny darter						2	45	16	33	2			98	0.7
Slimy sculpin	16	10	201	71	56	15	211	38	40	32	30	31	751	5.1
Unknown coregonids			1	1			5	2		1			10	<.1
Coho salmon							1						1	<.1
Longnose sucker							1						1	<.1
Gizzard shad		2	7	3							1	13	26	0.2
Bluegill			2	1				1					4	<.1
Ninespine stickleback			1	2			3						6	<.1
Channel catfish	3	2	4	2	3	1	2					3	20	0.1
Burbot			1						1				2	<.1
Green sunfish						1	2						3	<.1
Black bullhead	1		2	1			1	1	1				7	<.1
Yellow bullhead	1												1	<.1
Mudminnow	1		22	6	2	1							32	0.2
Rock bass		2				1							3	<.1
Pumpkinseed						1							1	<.1
Fathead minnow						1							1	<.1
Quillback												1	1	<.1
Total	146	30	2221	306	199	39	4761	5729	493	52	179	693	14848	

Table E3. A summary of fish impinged at the Cook Plant in 1973 (Jude et al. 1975, Impingement Section). Pumps were run for testing purposes and fish discarded by plant personnel during May-September 1973.

Species	Jan	Feb	Mar	Apr	Oct	Nov	Dec	Total	% of Total
Alewife				3			30	33	5.5
Spottail shiner	2	43	1	1			15	62	10.3
Yellow perch	10	25	1	1			221	258	42.9
Rainbow smelt		50	3	2		1	4	60	10.0
Trout-perch							1	1	0.2
Slimy sculpin	8	30	5	83	2	3	16	147	24.5
Channel catfish	4	1					2	7	1.2
Mudminnow			1	1				2	0.3
Black bullhead	4	2		6				12	2.0
Gizzard shad	1							1	0.2
Ninespine stickleback		5						5	0.8
Unknown coregonids						1		1	0.2
Burbot	1	1						2	0.3
Johnny darter				1		1		2	0.3
Pumpkinseed	1							1	0.2
Black crappie	1							1	0.2
Bowfin				1				1	0.2
Mottled sculpin							3	3	0.5
Northern pike							1	1	0.2
White sucker	1							1	0.2
Totals	33	157	11	99	2	6	293	601	

Table E4. Weight in kilograms of fish impinged on Cook Plant traveling screens during 1974.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	% of Total
Alewife	.11	.04	83.08	7.20	1.23	.14	131.66	155.54	6.12	.13	.28	12.65	398.2	92.2
Spottail shiner	.03	.02	.23	.08	.03		.30	.33	.08	.05	.01	.02	1.2	0.3
Rainbow smelt	.08		.80	.72	.16	.01	.48	.36	.19	.01	.03	.03	2.9	0.7
Yellow perch	.34	.03	.22	.20	.21	.03	1.54	14.09	1.71	.25	.44	1.96	21.0	4.9
Trout-perch	.01		.07	.03			.56	.48	.25		.02	.02	1.4	0.3
Johnny darter						.01	.14	.04	.08	.01			0.3	0.1
Slimy sculpin	.09	.05	1.35	.48	.29	.07	1.04	.29	.27	.21	.22	.20	4.6	1.1
Unknown coregonids			.01	.01			.20	.03		.01			0.2	0.1
Coho salmon								.12					0.1	0.1
Longnose sucker							.79						0.8	0.2
Gizzard shad		.03	.12	.04							.02	.19	0.4	0.1
Bluegill			.03	.01				.01					0.1	0.1
Ninespine stickleback			.01	.20			.01						0.2	0.1
Channel catfish	.01	.01	.03	.01	.01	.01	.26					.04	0.4	0.1
Burbot			.02						.14				0.2	0.1
Green sunfish						.01	.01						<0.1	0.1
Black bullhead	.01		.05	.03			.01	.07	.09				0.3	0.1
Yellow bullhead	.01												<0.1	0.1
Mudminnow	.01		.12	.03	.01	.01							0.2	0.1
Rock bass		.01				.01							<0.1	0.1
Pumpkinseed						.01							<0.1	0.1
Fathead minnow						.01							<0.1	0.1
Quillback												.01	<0.1	0.1
Total	0.7	0.2	86.1	9.0	1.9	0.3	137.0	171.4	8.9	0.7	1.0	15.1	432	

species accounted for less than 1% of the total weight.

Seasonal Occurrence and Abundance

Alewives, yellow perch and slimy sculpins were impinged every month during 1974 (Table E2). Spottail shiners were impinged every month except June, and smelt were collected every month except February.

Alewives were most abundant in March, July and August (Table E2), agreeing with our field data (Table B9) which showed alewives inshore during warmer months and offshore during winter. Unexpected large numbers of adult alewives were impinged in December 1974 and also in December 1973 (Table E3). It is unclear why adult alewives were inshore in cold weather, but one possibility is that they were fish in poor condition or strays which did not migrate offshore. On the other hand, they may have been seeking warmer inshore water as temperatures in December can be quite variable. In either case, low population density and limited field sampling in December would probably explain why we have no record of field-caught alewives in December 1973 or 1974 (a few were trawled in December 1975).

Largest impingement catches of slimy sculpins were in March and July 1974, although they were also plentiful in fall and winter months (Table E2). They are tolerant of cold temperatures (Rottiers 1965) and probably remain in the intake area all year. Few sculpins were impinged in April, though large field catches in April 1973 and 1974 (Tables B6 and B9) suggested they were most abundant in the area this month, probably as they moved inshore to spawn. Gonad data (Table B47) indicated that most specimens field-caught in April were gravid. Limited pumping during April 1974 may explain the low numbers impinged. Impingement data for 1975 supported the hypothesis of increased April impingement of sculpins.

Most yellow perch were impinged in December 1973 and 1974 (Tables E2 and E3) which was inconsistent with standard series catches. These catches indicated yellow perch were most abundant inshore in July and August, moving offshore to deeper water as water temperature dropped in autumn (Table B9). One possibility is a lengthy residence time in the forebay. Perch entering the forebay in autumn may reside there until physical deterioration and weakness cause them to be impinged. Such a lag time was found at the Zion Nuclear Plant in a tagging study of rainbow trout (Cochran 1976) and suggested by Wapora (1976) in their study at Presque Isle Power Station. Most perch impinged in December at the Cook Plant were YOY (Fig. E1). Wells (1968) suggests YOY perch may remain inshore when adults move into deeper water. Hergenrader and Hasler (1966, 1967 and 1968) noted that perch showed considerable movement even in winter, apparently in response to temperature or food availability. This movement as well as their tendency to school may explain why we impinged so many perch on 2 out of 3 days of sampling in December 1974. If schools of yellow perch move in and out of the inshore area, it may also explain why few perch were taken in gill nets set in December, as this sampling covered only one 24-h period.

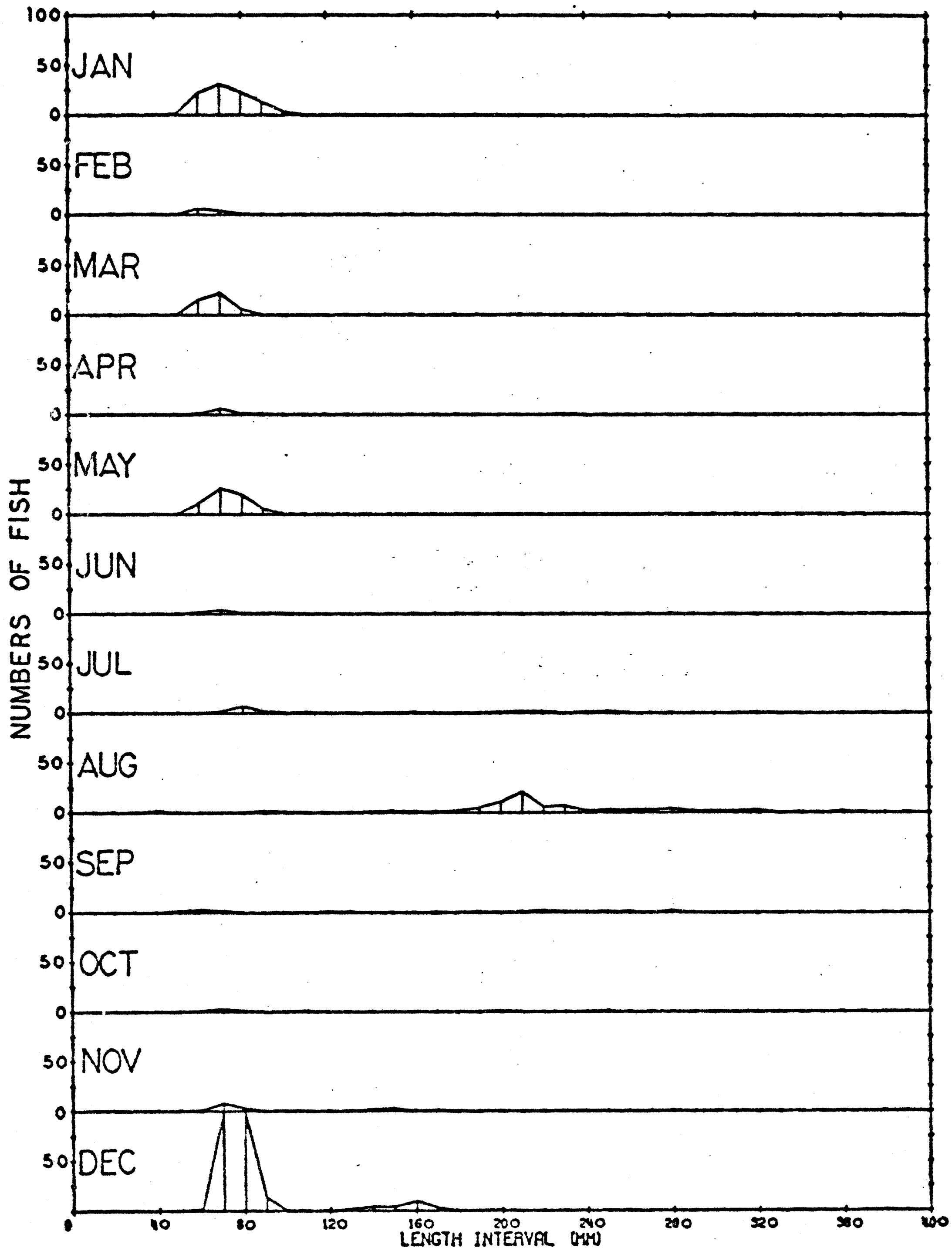

Fig. E1. Length-frequency histograms for yellow perch impinged on Cook Plant traveling screens during 1974.

Impingement catches of rainbow smelt were most abundant in spring and late summer (mostly YOY- Table E2), which was consistent with field data (Table B9). Only smaller smelt (YOY about 60-90 mm) were impinged from October through December (Fig. E2). Most adults had probably moved into deeper water by this time, a behavior noted by Wells (1968). Occasionally smelt entered the inshore area during fall and winter which was substantiated by low gill net catches in February 1973 (Table B6), trawl catches in October 1974 and gill net catches in October and December 1974 (Table B9).

Spottail shiners were impinged most often during March, July and August, although they accounted for only 0.5-1.0% by number of the total impingement catch for these months (Table E2). In January 1974, the 16 spottails impinged accounted for 11% of the total catch. Their presence in the inshore area the entire year was substantiated by 1974 standard series catches (see Table B9) and by the trawling efforts of Wells (1968). Fish larger than 90 mm dominated catches from February through November (Fig. E3); fish smaller than 70 mm dominated catches in December and January. Field catches indicated YOY were probably closer to the beach in summer. A few may have remained near the 9-m contour in winter when most adults returned to deeper water.

Very few trout-perch were impinged during 1974 (Table E2). They were most abundant in impingement samples during July, August and September, and absent from February, May, June and October collections; during these latter months the plant pumped a minimal volume of water. Trout-perch are largely restricted to depths less then 55 m in southeastern Lake Michigan (Wells 1968). Large numbers of trout-perch impinged through the fall and winter of 1975-1976 suggest that they were common at depths as shallow as 9 m during cold weather. They were not, however, collected in field samples at the Cook Plant in January through March or December 1974 (Table B9), probably because no trawling was done these months.

Impinged Fish Abundance in Relation to Field-Caught Fish

In 1974, 23 species were impinged compared to 32 species caught in standard series sampling. The following species were collected from the traveling screens but not from standard series collections: mudminnow, yellow bullhead, rock bass, pumpkinseed, quillback and fathead minnow. Of these species, only mudminnow was impinged regularly.

The most abundant species in impingement catches in 1974 were also most abundant among field-caught fish. The exception was slimy sculpins (751 impinged - Table E2) which was the second most abundant species impinged (5.1% of the total catch). Only 272 specimens (0.24% of the total catch) were collected from all standard series sampling (Table B9). Sculpins also accounted for a small proportion (0.5%) of the field catch at station D (9-m station closest to the intakes) (Table E5), suggesting that impinged sculpins were derived from a local population in the area of the riprap. Preference for a rocky area such as the riprap for concealment and spawning

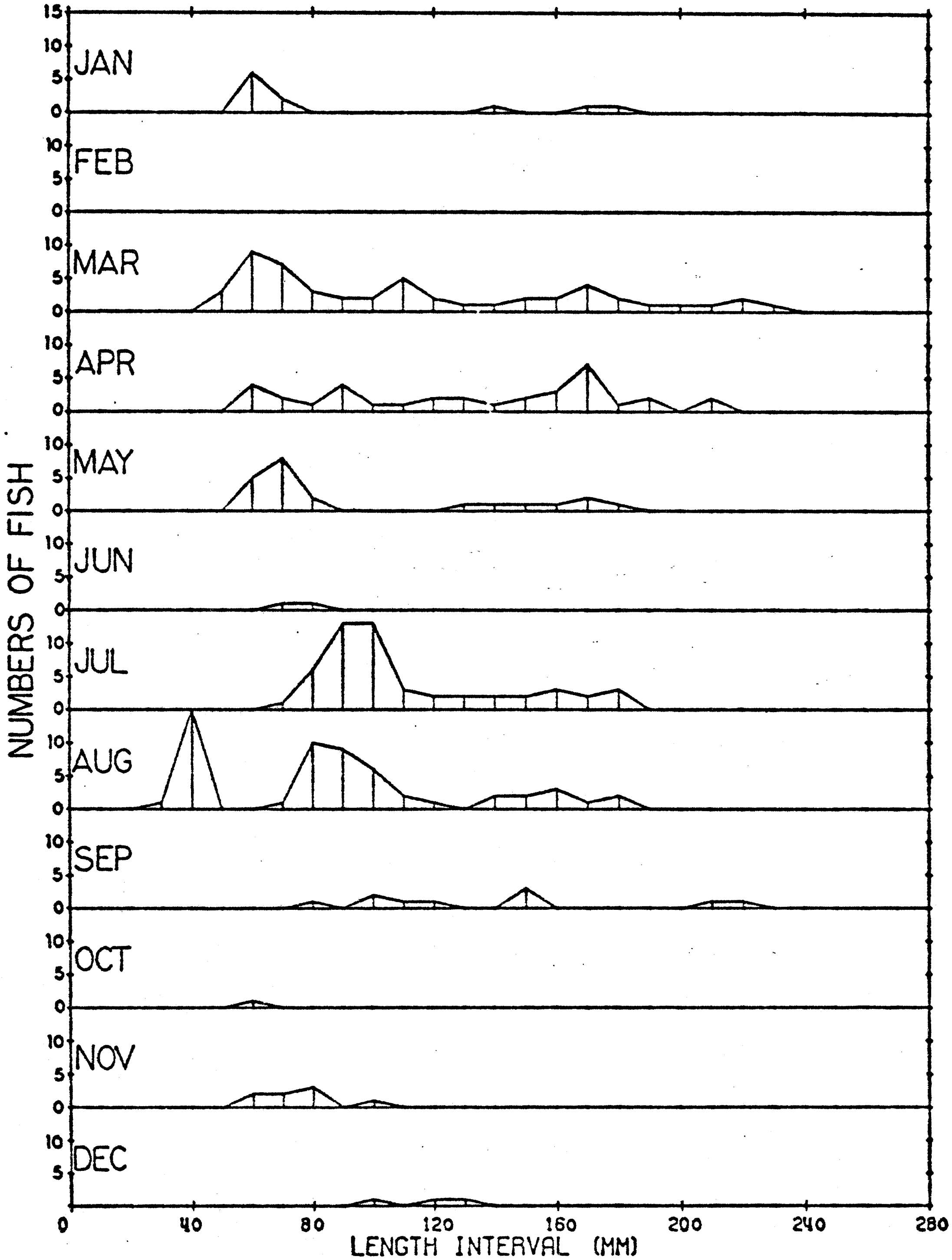

Fig. E2. Length-frequency histogram for rainbow smelt impinged on Cook Plant traveling screens during 1974.

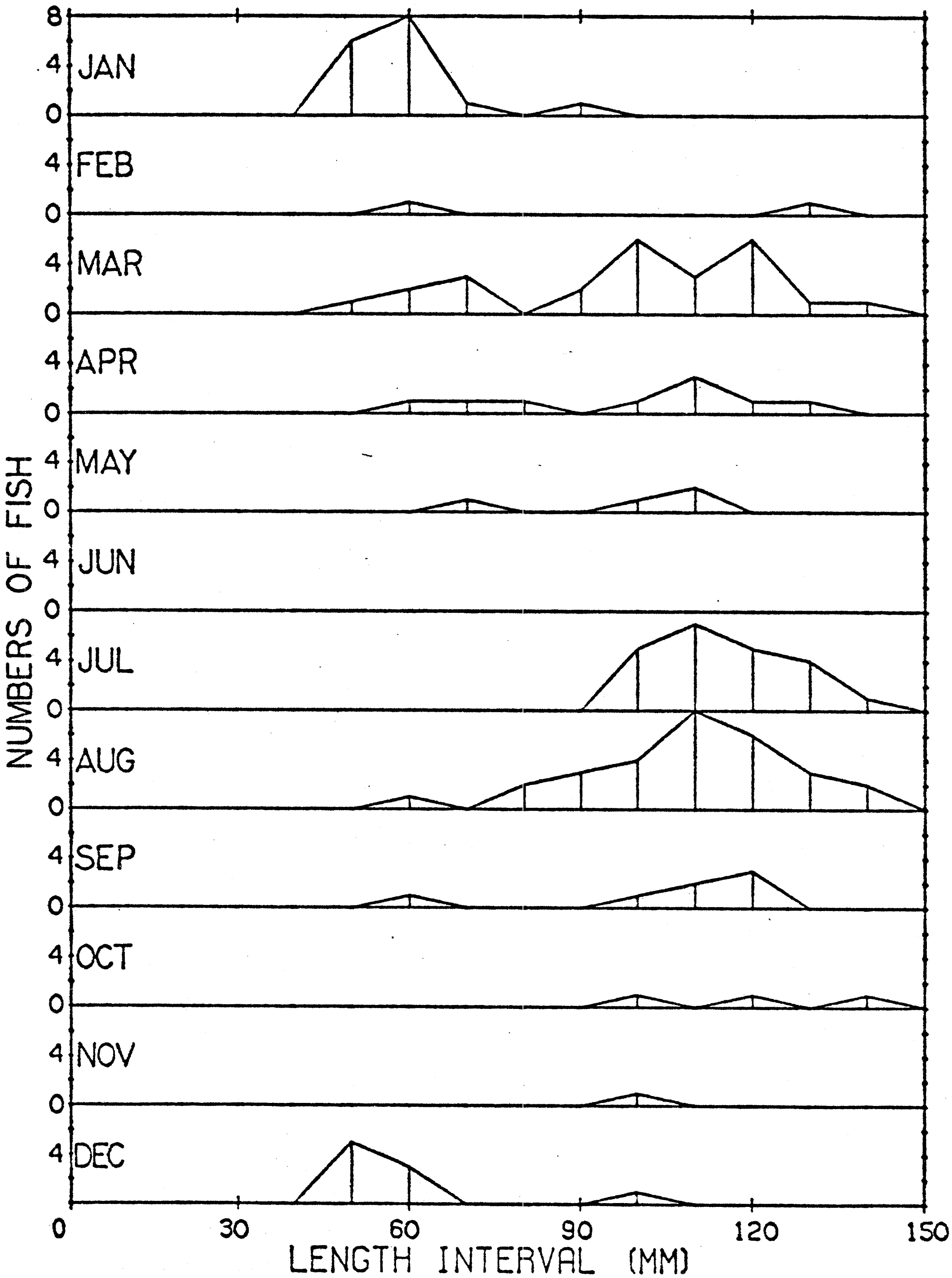

Fig. E3. Length-frequency histogram for spottail shiners impinged on Cook Plant traveling screens during 1974.

Table E5. Numbers of fish caught in 1974 standard series trawls and gill nets at Cook Plant Station D (9 m), that station nearest the intakes.

	Jan	Feb[1]	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	% of Total
Alewife	0	-	152	742	2016	1032	328	91	126	319	837	0	5643	54.2
Spottail shiner	1	-	48	76	939	784	3	6	22	118	7	17	2021	19.4
Rainbow smelt	0	-	15	141	320	7	287	835	28	188	1	1	1823	17.5
Yellow perch	0	-	8	16	9	28	1	77	175	7	29	8	358	3.4
Trout-perch	0	-	0	3	48	24	61	17	10	74	6	0	243	2.3
Johnny darter	0	-	0	0	26	10	1	2	3	11	7	0	60	0.6
White sucker	1	-	0	1	1	2	0	0	0	2	2	0	9	0.1
Longnose sucker	1	-	0	0	3	1	3	0	0	0	3	1	12	0.1
Lake trout	0	-	0	0	6	2	0	0	0	1	23	0	32	0.3
Chinook	0	-	0	0	0	0	0	2	2	0	0	0	4	<0.1
Carp	0	-	0	0	0	0	0	5	1	1	0	0	7	0.1
Coho	0	-	2	2	12	0	0	17	0	0	5	0	38	0.4
Brown trout	0	-	0	1	0	0	3	2	0	0	2	0	8	0.1
Ninespine stickleback	0	-	0	0	3	2	1	0	0	0	0	0	6	0.1
Slimy sculpin	0	-	0	40	4	1	2	0	0	9	5	0	61	0.6
Channel catfish	0	-	0	0	0	0	0	0	1	1	0	0	2	<0.1
Northern pike	0	-	1	1	0	0	0	0	0	0	0	0	2	<0.1
Gizzard shad	0	-	0	0	0	0	0	0	1	3	0	0	4	<0.1
Unknown coregonids	0	-	0	0	1	1	61	1	0	5	0	0	68	0.7
Lake whitefish	0	-	0	0	0	0	0	1	0	0	0	0	1	<0.1
Burbot	0	-	1	0	0	0	0	0	0	0	0	2	3	<0.1
Total	3	-	227	1023	3387	1894	751	1056	369	739	927	29	10405	

[1]No standard series fishing was done in February.

(Hubbs and Lagler 1964, Scott and Crossman 1973) probably contributed to the vulnerability of sculpins to impingement. Observations by divers confirmed the abundance of sculpins and their spawning activities in this area (Dorr 1974b, Dorr and Miller 1975).

Among other major species, several discrepancies occurred between abundance exhibited in field and in impingement samples. Alewives were the most abundant species in both collections, accounting for 85.5% by number of the impingement catch (Table E2) but only 66.8% of the total standard series catch and 60% of the catch at station D. Alewives accounted for a slightly smaller percentage of the total 1975 field catch than in 1974 due to more complete data from winter months of 1975 when alewives were less abundant; however, they still comprised over 75% of the 1975 impingement catch. Divers often observed alewives schooling in the area of the intakes during May-October, which suggests that this species may be attracted to the area, thereby increasing their vulnerability to impingement.

Spottails and rainbow smelt were under-represented in impingement samples when compared to their abundance in field samples. At 9-m station D, spottails accounted for 17.0% of the field catch and smelt accounted for 15.4% (Table E5). In contrast, spottails accounted for 0.9% of the impingement catch and smelt accounted for 1.7%. The dearth of spottails impinged can be explained by their distribution and plant pumping schedules. Spottails were most abundant in the trawling zone in the spring during their inshore migration, but from April-June the plant was circulating water sporadically, if at all. During July and August, when circulation pumps were run regularly, spottails had moved shoreward of the 6-m contour into the beach zone (see SECTION B, Spottail Shiner). One possible explanation for the paucity of smelt in impingement catches is avoidance of the riprap area. Smelt were never observed near the intakes by divers (Dorr and Miller 1975). They were, however, abundant at 9 m during July and August, but were mostly of a size range (yearlings 35-64 mm) which might pass through the 9.5-mm mesh of the traveling screens. Of the 835 smelt trawled in August from station D, 800 were 25-44 mm (see SECTION B, Rainbow Smelt).

YOY of all species were negligible in traveling screen catches, as few fish under 50 mm were impinged (Figs. E1-E6). One possibility is that YOY tend to remain at shallower depths -- largest numbers of YOY alewives, spottails and smelt in field catches were collected by seining (see respective sections). It is also possible that smaller sizes of fish slip through or are forced through the 9.5-mm mesh of the traveling screens or are impinged only when the screens are most clogged just before washing. YOY and yearling perch were impinged in December (Fig. E1) and from January through July. These fish were slightly larger (65-94 mm) and their occasional presence at the 9-m contour was confirmed by trawling (see SECTION B, Yellow Perch). The size range of larger fishes impinged was fairly representative of sizes caught in standard series sampling.

Because of more extensive pumping in 1974 than in 1973, considerably

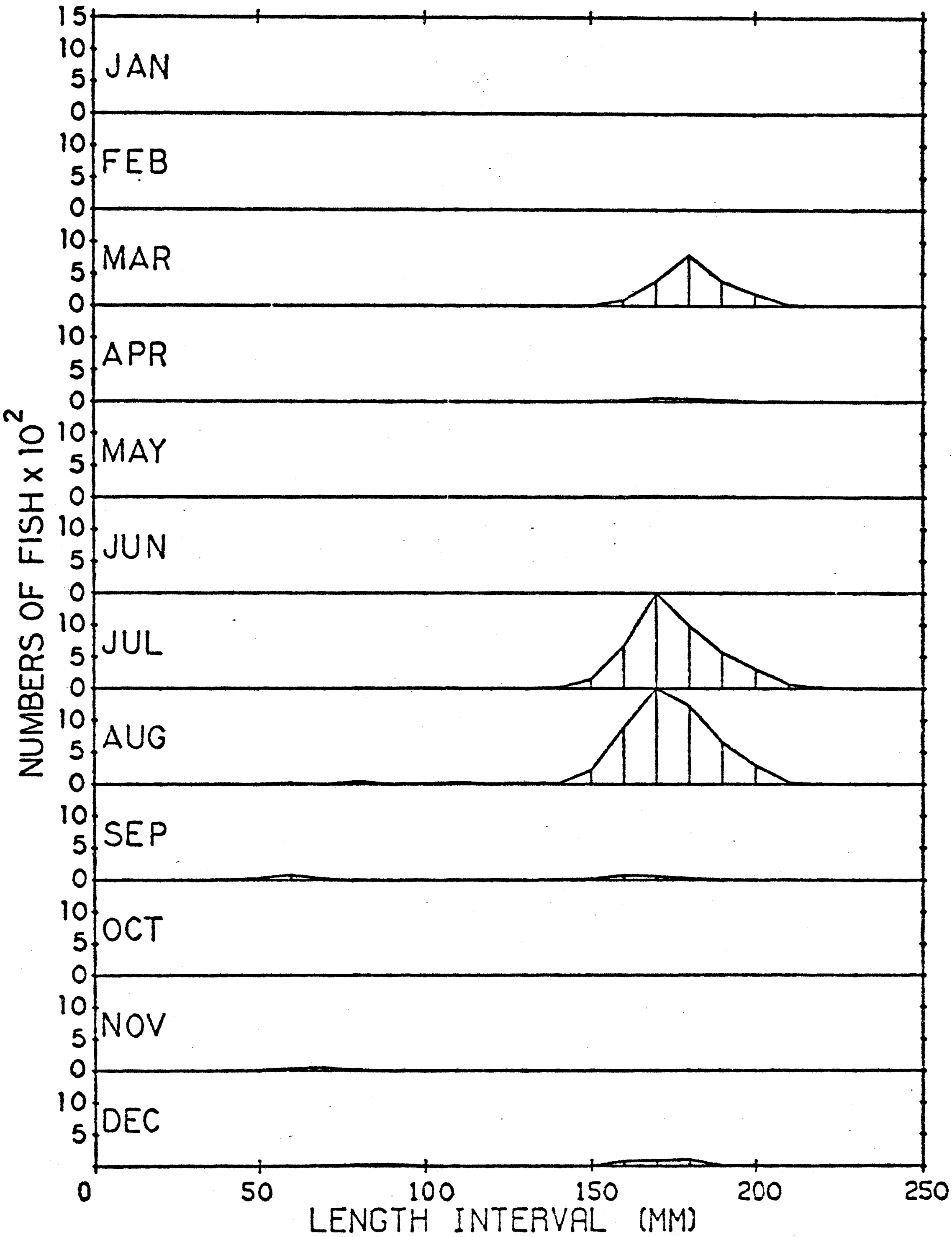

Fig. E4. Length-frequency histograms for alewives impinged on Cook Plant traveling screens during 1974.

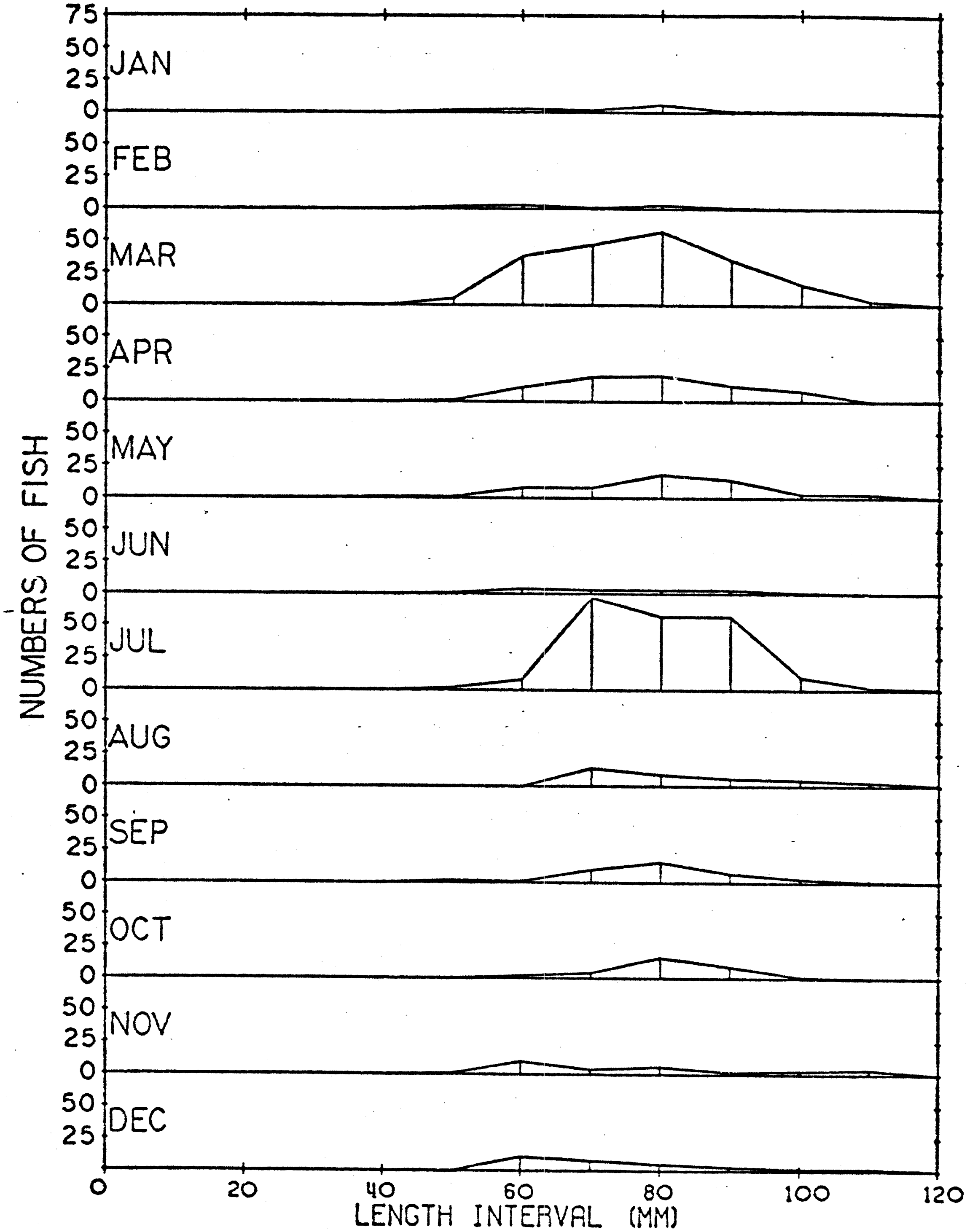

Fig. E5. Length-frequency histograms for slimy sculpin impinged on Cook Plant traveling screens during 1974.

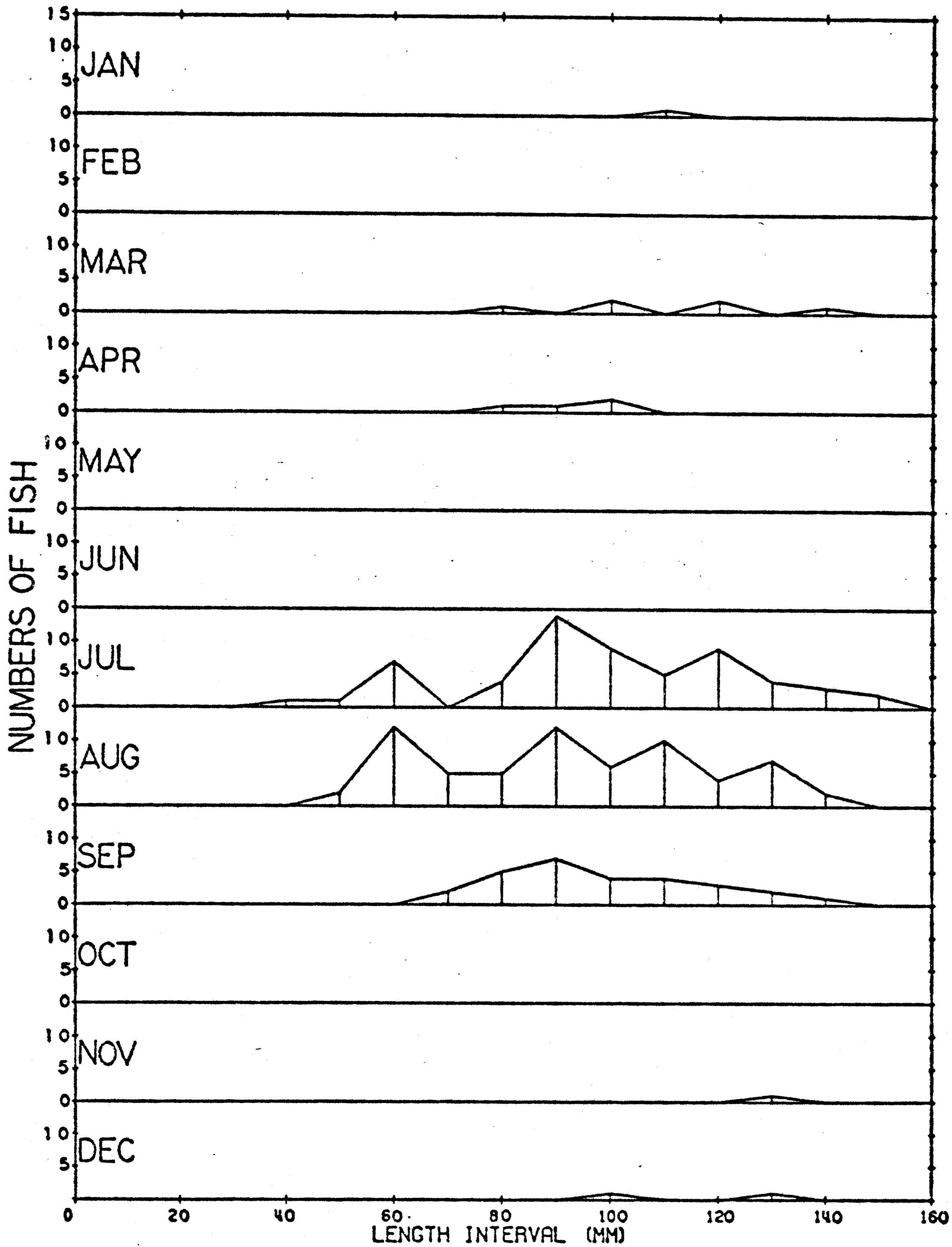

Fig. E6. Length-frequency histograms for trout-perch impinged on Cook Plant traveling screens during 1974.

more fish were impinged. Increased data made it possible to explore the question of whether or not impinged fish were in poorer physical condition than field-caught fish. "Condition" for our purposes was described by length-weight regressions and should not be confused with the conventional "K" or "C" condition (Carlander 1969, pp. 13-14).

The species initially chosen for the study were the six most common in impingement and field samples: alewife, smelt, spottail shiner, yellow perch, trout-perch and slimy sculpin. Further analysis of each species was completed on males and females separately to allow for sexual dimorphism. Damaged fish were excluded from analysis to reduce error in length and weight measurements. In addition there was some question as to the correctness of combining gill nets with other field gear, since in general gill nets are selective for a particular size (girth) of fish (dependent on mesh size) (Carlander 1953 and Heard 1962). Such pooling could introduce a bias into length-weight relationships, thus statistical testing was also performed to clarify this problem.

The initial analysis framework called for separate tests each month to reduce effects of varying stages of maturity and sexual condition. Preliminary tests were run to determine the possibility of combining some months and thereby increasing sample size. Highest impingement catch values occurred in March, July and August 1974. Covariance tests were run on adjacent months with data stratified by gear, species and sex. Results of these tests justified combining sculpin data from March and April, but differences in length-weight relationships prohibited further combinations ($\alpha = 0.10$). Analyses were completed on alewives from July and yellow perch from August. Numbers of other species were too small to test for differences between impinged and field-caught fish. Significant differences ($\alpha = 0.10$) between regression equations for alewives caught in gill nets and other field gear for both male and female alewives and also (marginally) for male yellow perch necessitated testing of impinged fish of these species separately against gillnetted fish and fish caught by other gear. Much of this difference can be attributed to size, for gill nets sampled mostly adult fish, while YOY were proportionally over-represented in samples taken with other gear, especially seines. Female yellow perch, however, showed no difference in length-weight regressions between gillnetted and seined or trawled fish, and these two groups were combined for comparison with impinged fish. Sculpins were not caught in gill nets in sufficient numbers for analysis.

Of the three species examined, only alewives showed a difference in condition between impinged individuals and those caught in the field (Tables E6 and E7). The slopes of the length-weight relationships were equal for both groups, but regression intercepts were not equal and adjusted mean weight was significantly less for impinged fish. This relationship was also evident when impinged male alewives were compared with male alewives caught by seine and trawl. Impinged males weighed approximately 10% less than field-caught males. Female alewives showed a less clear relationship between field-caught and impinged fish. Slopes were not equal; regression

Table E6. Length-weight regression equations for alewives, yellow perch and slimy sculpins impinged, caught in gillnets and in other gear (seines and trawls) in the vicinity of the Cook Plant, southeastern Lake Michigan 1974.

Gear	Sample Size	Regression equation	R^2
		Alewife -females-July	
Impingement	329	Log W = -4.1732 + 2.5222 (Log L)	.71
Gill net	143	Log W = -3.8675 + 2.4267 (Log L)	.87
Seine & Trawl	119	Log W = -2.6255 + 1.8708 (Log L)	.48
		Alewife -males-July	
Impingement	269	Log W = -3.7259 + 2.3194 (Log L)	.61
Gill net	102	Log W = -2.7736 + 1.9220 (Log L)	.57
Seine & Trawl	222	Log W = -3.5700 + 2.2709 (Log L)	.73
		Yellow perch -females-August	
Impingement	24	Log W = -5.5367 + 3.2647 (Log L)	.99
Gill net & Seine & Trawl	220	Log W = -5.5971 + 3.2778 (Log L)	.96
		Yellow perch -males-August	
Impingement	38	Log W = -5.5255 + 3.2314 (Log L)	.50
Gill net	70	Log W = -5.4975 + 3.2294 (Log L)	.99
Seine & Trawl	86	Log W = -5.3841 + 3.1847 (Log L)	.98
		Slimy Sculpin -females-March, April	
Impingement	168	Log W = -5.2846 + 3.2243 (Log L)	.91
Seine & Trawl	106	Log W = -5.4682 + 3.3213 (Log L)	.92
		Slimy sculpin -males-March, April	
Impingement	70	Log W = -5.6916 + 3.4274 (Log L)	.92
Seine & Trawl	44	Log W = -4.6942 + 2.9114 (Log L)	.84

Table E7. Analysis of covariance for impinged vs. gillnetted and impinged vs. seined plus trawled alewives, yellow perch and slimy sculpins. Alewives were caught in July, yellow perch in August and slimy sculpins in March-April 1974. I = impingement, G = gillnetted, ST = seined and trawled. * = significant at α = 0.05.

		Test for slopes			Test for intercepts		
	Sample size	df	*F*	signif.	df	*F*	signif.
Alewives, female							
I x G	472	1,468	.45710	.4993	2,468	140.56	.0000*
I x ST	448	1,444	9.3851	.0023*	2,444	82.501	.0000*
Alewives, male							
I x G	371	1,367	2.4681	.1170	2,367	53.656	.0000*
I x ST	491	1,487	.10857	.7419	2,487	43.466	.0000*
Yellow perch, female							
I x G + ST	244	1,242	.00956	.9222	2,240	.98401	.3753
Yellow perch, male							
I x G	108	1,104	.00358	.9952	2,104	.64123	.5287
I x ST	124	1,120	.01943	.8894	2,120	.59118	.5553
Slimy sculpin, female							
I x ST	274	1,270	.61179	.4348	2,270	.37457	.6879
Slimy sculpin, male							
I x ST	114	1,110	4.3539	.0392*	2,110	2.3108	.1040

equations for impinged females had a steeper slope than field-caught females. Field-caught females were represented by a distinctly smaller size range than impinged females, smaller individuals in particular being poorly represented in field collections. As with males, weights between the two groups of females were significantly different. Within the size range 155-205 mm, which included most individuals, impinged fish weighed from 9% to 24% less than field-caught fish.

Neither male nor female yellow perch showed any significant difference between slopes or regression intercepts of impinged fish and those of field-caught fish, indicating no difference in length-weight relationship between the two groups.

No evidence was found of impinged sculpins being in any poorer condition than field-caught fish. Length and weight of impinged females were no different from those caught with seine or trawl. Regression equations of impinged male sculpins, when compared with field-caught males, had different slopes, with regression slopes for impinged males being somewhat steeper (Tables E6 and E7). Regression lines for the two groups intersected near the adjusted mean weight and it was not apparent that weights of impinged fish were either lower or higher than weights of field-caught fish. If impinged sculpins were drawn from a localized population in the area of the riprap, then differences in length-weight regressions between impinged sculpins and those caught in the field may represent differences between two distinct populations.

Results of alewife comparisons suggest the possibility that the plant is culling individuals of poorer condition than those caught by field methods. There is no evidence of this, however, in the populations of yellow perch or slimy sculpins which were compared. Many more fish have been collected in 1975 and analysis of these data should allow more thorough comparisons, involving more species and months.

Although results obtained from 1974 data are somewhat ambiguous, they still present the question of what mechanism would result in the impingement of less robust alewives and why yellow perch and slimy sculpins are not similarly affected. One possibility is that weaker alewives are selected at the intake structure itself. Though found in the area, healthy and normally pelagic adult alewives may seldom enter the intakes; however, weaker individuals may be attracted to the darkness and protection of the structure. Current velocities for Unit 1 approximate 0.4 m/s at the inlet of the intake structure and 1.8 m/s within the intake pipes. There is no evidence that this current draws fish into the intake; however, it may influence the fish, and weakened alewives may be less likely than healthy fish to resist. Yellow perch and slimy sculpins are more demersal than alewives, and individuals might be attracted to the shelter of the intakes, thus the structure should not be selective for weaker members of these species.

Another possibility may be that normal populations of all three species may enter the intake pipes. Once in the forebay, alewives may avoid the area of the trash racks, resisting the current (0.3 m/s) and remaining in the forebay until greatly weakened, or dead. Sculpins and perch may be less likely to attempt to remain in the open area of the forebay, with subsequently less delay between time of entering the forebay and time of impingement. Preliminary analysis of 1975 impingement data suggests that peak numbers of alewives were impinged 2 to 4 days following storms. A similar relationship was observed at Palisades Nuclear Plant (J. Gulvas, personal communication, Consumers Power Co., Jackson, Mich.). This 2- to 4-day lag confirms the likelihood that alewives remain in the forebay a period of time before being impinged.

GENERAL SUMMARY

In our statistical section, we developed methods for evaluating data based on abundance indexes derived from catch-per-unit-effort data. Four gear types were used to sample fishes: trawls, seines, gill nets and plankton nets. Impingement data provided additional information. Each gear has an associated bias, but a composite of gear with consistent sampling methodology manifesting relatively constant bias and overlapping knowledge provided a mechanism for evaluating fish populations over time and space.

Parametric testing for spatial and temporal differences in the number of fish collected utilized balanced full-factorial model I (fixed effects) analysis of variance (ANOVA) at the 0.01 level of significance. Distributional properties of data were examined and a $\log_{10}$ (catch + 1) transformation was applied to normalize its distribution and reduce inequality of variance. Some data matrices were reduced to lower the percentage of zero catches thus reducing bimodalization and/or negative skewness. Assumptions of ANOVA related to the data (normal distribution of residuals, homoscedasticity of common cell variances and independence of sampling) were rigorously tested; those data failing to approximate assumptions acceptably were excluded from parametric analysis.

A priori (planned comparison) F-tests were conducted on all main effects and interactions; _a posteriori_ comparisons were not conducted. Back-transformed means of log-transformed data, equivalent to geometric means of original data, were plotted to augment interpretation of non-additive ANOVAs, i.e., those with significant interactions. Significant higher-order interactions were often difficult to interpret and partly obscured the relationship between main factors. Future analysis of non-additive ANOVAs utilizing simple and multiple orthogonal contrasts whenever possible will be considered.

Alternate treatments and parametric analyses of data discussed in Section A (Experimental Design and Statistical Methods) included: negative binomial transformation of data where the variance is significantly greater than the mean, use of analysis of covariance (ANCOVA) to reduce obscuring variance of a factor (covariate) such as water temperature during factorial analysis, and analysis of preoperational-operational data by control charting incorporating time as a linear factor, correcting for seasonal variation and establishing action limits representing confidence limits about the mean. Also anticipated is further investigation into merit and future application of these analytical procedures to increase the power of analysis thereby detecting smaller differences as significant.

Statistical analysis utilizing nonparametric tests was conducted on data that failed to approximate assumptions of ANOVA acceptably. Sign tests for differences between means and Wilcoxin signed ranks tests for magnitude of differences were conducted on combined 1973, 1974 gill net data paired by month. Type I error accepted ($\alpha = 0.10$) was larger than error accepted for

ANOVA to increase the power and comparability of our nonparametric test results to parametric test results, given that parametric tests are more power efficient under conditions of normality. Continued and expanded nonparametric testing of non-normally distributed data is anticipated in future analyses.

Trawl data (alewife, spottail shiner, rainbow smelt, yellow perch and trout-perch) were subjected to a five-way ANOVA with two replicates per cell. Distributional properties of combined 1973, 1974 trawl data differed slightly from 1973 data but coefficients of dispersion were high in all cases, indicating contagious fish distributions, an intrinsic property of many fish and other biological populations. Interpretation of main effects of spatial and temporal factors for alewife, spottail shiner and rainbow smelt ANOVAs was complicated by significant third-order interactions for all main factors. Yellow perch and trout-perch ANOVAs were less complex since AREA did not enter into any significant interactions and other factors were involved in, at most, second-order interactions. Least detectable true changes (LDTC) in geometric mean abundance ranged from 1.46 for spottail shiner to 1.78 for alewife ($\alpha = 0.01$, power = 0.95), which were slightly higher than LDTCs predicted in Tables A3-7 of Jude et al. (1975) due to increased mean-square error of 1973-1974 combined ANOVA over that calculated from 1973 data alone. Thus, an approximate 1.5- to 1.8-fold increase or 40-50% decline in relative abundance would be detected depending upon species. These LDTC values indicate an encouraging level of sensitivity to change incorporated into our experimental design, given the complexity and scope of variation characteristic of Lake Michigan fish populations.

Seine data (alewife and spottail shiner) were subjected to a four-way ANOVA with two replicates. Failure of rainbow smelt, yellow perch and trout-perch data to approximate assumptions acceptably prompted their exclusion from parametric analysis; high percentage of zero catches also precluded nonparametric analysis. Distributional properties of combined 1973, 1974 seine data differed somewhat from 1973, but coefficients of dispersion remained high, indicating beach zone fish distributions were also clumped. Significant third-order interactions for all main effects complicated interpretation of alewife ANOVA. For spottail shiner ANOVA, station did not enter into any significant interactions although significant second-order interactions among other main factors occurred. Least detectable true changes (LDTC) for seine ANOVAs (alewife - 2.23, spottail shiner - 2.60) were distinctly larger than trawl LDTC values; changes in fish abundance judged significant by trawl ANOVAs would not be detected in seine ANOVAs. Loss of sensitivity (power) of seine relative to trawl ANOVAs was attributed primarily to smaller sample sizes and fewer degrees of freedom. Also, for spottail shiner, mean-square error (MSE) was three times larger than MSE of trawl ANOVA; for alewife, MSE of trawl ANOVA was slightly larger than MSE of seine ANOVA.

Gill net data for spottail shiner were subjected to a five-way ANOVA with one observation per cell. The fourth-order interaction was assumed to be zero and its mean-square was used as an estimate of MSE of ANOVA.

Alewife, rainbow smelt, yellow perch and trout-perch data failed to approximate assumptions of ANOVA acceptably and were subjected to nonparametric testing. Distributional properties of combined 1973, 1974 gill net data were similar to 1973 data and the coefficient of dispersion remained high. All main factors were involved in significant second-order interactions except DEPTH which entered into significant first-order interactions, thus complicating interpretation of main effects. Least detectable true change (LDTC) was calculated to be 1.72, indicating that gill net ANOVA was slightly less powerful than spottail shiner trawl ANOVA. For nonparametric analysis, data were paired by MONTHs (MONTH was assumed to be a significant factor) thereby masking any interactions involving MONTH; results of testing for other main effects are summarized in Tables B17, B20, B35 and B41.

Plankton net data were not subjected to statistical analysis. Future analyses utilizing parametric (ANOVA) and nonparametric procedures are anticipated.

Preoperational ANOVAs revealed that potential to detect Cook Plant effects is good. Three ANOVAs (alewife in trawls and seines and spottail shiner in seines) should ascertain both plant and non-plant effects. Four other ANOVAs (spottail shiner, yellow perch and trout-perch in trawls and spottail shiner in gill nets) should ascertain plant effects alone. Only one ANOVA (rainbow smelt in trawls) will present difficult analysis relying upon multiple comparison tests for interpretation. Numbers of other species of fish captured in Cook Plant study area are presently anticipated to be insufficient to justify statistical analysis.

Statistical procedures can only detect statistical significance (at specified levels of significance and power) i.e., a difference in fish abundance that is too large to be considered an effect of random variation. Interpretation of statistical inferences must be couched in a solid understanding of underlying biological processes as they relate to analysis of fish populations.

In section B, the distribution and seasonal changes in the various age-groups of adult fish were discussed. Gear methodology for the capture of these fish was similar during 1973 and 1974. We concluded that fishing effort was comparable between the 2 yr, although approximately 8% more fishing occurred during January, March, November and December of 1974 than in 1973. From May 1972 to December 1974, 47 fish species were captured or impinged at or near the Cook Plant. In 1973, 31 species were captured by standard series nets while 32 species were collected in 1974.

During the two preoperational years, total catch per month varied (at times considerably) between months, seasons and years. In general greatest numbers and species of fish were found in summer months while lowest numbers occurred in winter. Some of the variability in catch between months was attributed to water temperature, which also, along with natural population changes, influenced yearly catches. In general, five major factors were

found to influence fish distributions in the study area - temperature, sexual activity, diel activity, schooling behavior and feeding activity.

The greatest numbers and species (73% of the year's total catch in 1973 and 64% in 1974) of fish were caught by seining while trawling contributed 23% of the 1974 catch and gillnetting 12%. Beach waters served as an important habitat for many species, some using it as a nursery area. While more fish were caught during the day than at night in seines and trawls; more were caught at night in gill nets. Also more species were caught at night compared to day by all three gear.

Upwellings (approximately seven per year from June to September occurred in the study year) were found to greatly affect spatial distribution of fish in the vicinity of the Cook Plant. Because the extent and intensity of upwellings vary considerably, effects on fish distributions were quite variable especially for warm-water species. However, cold-water species (especially smelt and bloaters) were found to move inshore with the thermocline and colder hypolimnetic water.

As an indicator species for possible plant effects, alewife had the advantage of being very abundant in the study area. Thus low numbers of alewives will not be a problem in the future when alewife data are analyzed for plant effects. Major problems in the 1973-1974 preoperational data interpretation involved determining whether biological trends in the alewife data varied as a function of temperature or whether they were influenced by other factors. If biological patterns were temperature-related, was temperature the primary factor or were there other influences of equal or greater importance? Biological patterns in the alewife catches of 1973-1974 that were influenced by temperature to some extent included: onset, duration and extent of annual shoreward migration of alewife adults; onset of spawning and month of maximum alewife spawning activity; and catches of alewife YOY primarily in warm beach zone waters. Other biological events affecting yearly variation in alewife catches in the study area were lakewide migration, lakewide abundance and diel activity patterns.

Much of the variation in statistical tests involving the significant main effects of DEPTH, TIME and AREA was attributed to variation in alewife catch size and distribution as a result of extensive schooling, vertical migration, alongshore migration and inshore-offshore migration. These biological factors may make detection of plant effects on the local alewife population difficult in the future.

Overall, seasonal patterns of alewife abundance in the study area (MONTH parameter) were a more predictable feature of local alewife biology than trends of abundance examined with respect to YEAR, DEPTH, AREA and TIME. However, it was clear from the 1973-1974 field data that effects of the Cook Plant on any of the factors studied (YEAR, DEPTH, TIME, AREA, MONTH) would have to be sizable in order to be detected against the natural variability of the alewife population in the study area. We feel that impingement and entrainment data will present more direct and quantifiable

evidence of the extent of plant impact on alewife than will field data.

Spottail shiners were the second-most abundant fish collected in 1973 and 1974. Their spring inshore migration began in March 1974 and abundance peaked in June. Spawning occurred in the study area during June and July. Recruitment of YOY to standard series gear occurred in August 1973, while in 1974 it first occurred in July. Spottails began migrating to deep water in September and October. During the winter a few spottails were netted indicating (along with winter impingement) that some individuals stay near 9 m.

Most spottails were caught by seining (72% of the total catch) especially by day seining in the summer. Nocturnal catches were higher than diurnal catches for gill nets and trawls especially in spring and fall. The spring inshore movement caused high gill net and trawl catches at 6 and 9 m as did the fall offshore movement. During summer most fish were inshore at 6 m and were concentrated during the day in the beach zone. At night they moved out of the beach zone apparently to slightly deeper water to spawn. The natural variation in spottail catches was the result of seasonal migrations, diel movements, schooling behavior, upwellings and yearly variation in rate of warming and cooling of the inshore water temperature. This natural variability resulted in the main ANOVA factor YEAR being significant for trawl and gill net catches. Although AREA (station) was not a significant factor in the ANOVA for all three gear, there were significant interactions involving AREA. The vast amount of natural variability observed will make determinations of plant-induced changes in spottail distribution and abundance very difficult to substantiate statistically.

Young-of-the-year spottails grew better and were more abundant in 1973 than in 1974. Warm temperatures and fair weather conditions in summer 1973 were apparently conducive to spottail spawning and growth in the study area. Spottails preferred warm water although larger fish were caught in cooler water than smaller fish. Spottails were seldom eaten by piscivorous fish. A myxosporidian infection was found in some spottails.

Rainbow smelt distribution in Lake Michigan was strictly regulated by age-group. Adults were confined primarily to offshore waters (21 m and deeper) except during spawning and upwellings. Young-of-the-year smelt utilized the area encompassing the 6- and 9-m contours as a nursery area from April through July. From August through October YOY smelt gradually moved offshore until by November they occupied water beyond the 9-m contour. Yearling smelt occupied the 6- and 9-m contours in early spring and may have ranged somewhat further inshore during this time. Yearling smelt remained at the 6- and 9-m contours until June, at which time they started to migrate to deeper water. By October yearling smelt distribution began to overlap that of the adults.

Temperature preference of smelt varied with age-group as did depth distribution. Adult smelt demonstrated a temperature of highest catch at 6-8 C. Young-of-the-year smelt were most often caught at 12-14 C while yearlings preferred 10-12 C.

No apparent difference in growth rate was evident for YOY smelt between 1973 (0.26 mm/day) and 1974 (0.30 mm/day). There was, however, an apparent difference in growth rate for yearling smelt between 1973 (0.26 mm/day) and 1974 (0.34 mm/day). The pattern of growth for YOY and yearling smelt, however, remained constant between years. YOY smelt exhibited the most rapid growth during spring while yearling smelt grew fastest in the fall.

Analysis of variance on smelt trawl catch data identified four significant main effects: YEAR, MONTH, AREA and DEPTH. The observed significant main effects, and the accompanying interactions, were due to yearly fluctuations in smelt population density, seasonal movements of different smelt age-groups through the sampling areas and upwellings during sampling. Significance of YEAR and AREA in our preoperational data will confound comparisons of these data for determination of plant-induced effects upon the smelt population.

Temporal and spatial distributions of smelt in the Cook Plant vicinity appeared to be stable between years. There appeared, however, to be a large natural fluctuation in yearly smelt population size.

Yellow perch were only abundant in the study area during summer and early fall, but they were present in low numbers throughout the rest of the year. Low numbers caught in May and June 1974 (when spawning occurred) indicated yellow perch do not extensively spawn in the study area.

In 1974 seining accounted for 74% of the total catch while gillnetting contributed 19% and trawling 7%. Trawling data showed a 81% decline in catch in 1974 compared to 1973. In general, all age-groups were caught in lower numbers in 1974, except yearlings, whose numbers tripled in 1974 compared with 1973. We believe that warmer water temperatures in summer 1973 caused a greater abundance of perch in the study area compared to more average years like 1974. While ANOVA of trawl catches showed a significant difference between years, there was no significant difference between area mean catches. Thus power plant effects on the Cook study area perch populations can be detected by comparison with Warren Dunes control area catches, but comparisons between preoperational and operational years will be very difficult to substantiate statistically. Catch data also showed increased diurnal activity over nocturnal activity and inshore movement at dusk by yellow perch in the study area.

Summer growth rate of YOY perch was considerably higher in 1973 (0.96 mm/day) than in 1974 (0.62 mm/day). Growth rate of yearlings in 1973 was also greater than in 1974. Abundance of the 1973 year class was high compared to the 1972 and 1974 year classes. Growth and reproduction of perch in 1973 was probably enhanced by warm summer temperatures.

Yellow perch were most often caught between 18 and 24 C. Larger perch were generally caught in cooler temperatures than smaller perch. Most larger perch ate alewives, but slimy sculpins and spottail shiners were also

consumed in moderate numbers.

Significant main effects (1973-1974 trawl ANOVA's) YEAR, MONTH, DEPTH and TIME resulted from highly variable data related to trout-perch abundance, distribution and seasonal and diel migrations. Non-parametric statistics applied to gill net data identified TIME and AREA as significant.

Because trout-perch are primarily benthic, they were most representatively sampled with our bottom trawl. Gill net catches of trout-perch were generally small and were not highly sensitive to changes in trout-perch abundance because gill nets underestimate abundance of smaller trout-perch due to mesh-size bias. Seine catches were also low; we are not sure why trout-perch avoided the beach zone although low abundance of benthic food organisms may be the cause.

Seasonal patterns of trout-perch were relatively predictable and undoubtedly affected by water temperature, although temperature preference was not found to be age or size dependent. Unfortunately, so little is known about trout-perch temperature preference that only general inferences could be made about the relationship between trout-perch seasonal abundance and Lake Michigan temperature regimes in the study area. Young-of-the-year trout-perch did not exhibit the marked preference for warm water exhibited by YOY of many other species. Therefore, trout-perch should not be extensively attracted to the heated plume during April-October.

Statistical and non-statistical evaluation of trout-perch data revealed a shoreward nocturnal movement characteristic of this species. Such movements usually occurred independently of water temperature (except in winter) or spawning season. While trout-perch nocturnal shoreward migration in preoperational years was occasionally interrupted, it was usually a predictable part of trout-perch behavior. Significance of YEAR in the 1973-1974 ANOVA's will confound the use of ANOVA's to detect potential operational effects of the plant between preoperational and operational years. However, changes such as a prolonged disruption of this species' nocturnal shoreward migration would be considered atypical and possibly a consequence of plant operation. Radical changes in trout-perch abundance in the Cook Plant vicinity, especially in the beach zone, would also present the possibility of plant effect.

Johnny darters were the sixth most abundant fish caught in both 1973 and 1974. They were trawled in the Cook Plant area all year, but most often during the May-July spawning season. Johnny darters were more numerous in 1974 when large numbers of yearlings led us to believe 1973 produced a particularly strong year class. Depth distribution of johnny darters at Cook (larger catches at 6 m than at 9 m) contrasted with depth distribution at Warren Dunes (larger catches at 9 m than at 6 m) may reflect a possible attraction of johnny darters to the Cook Plant riprap.

Slimy sculpin was also one of the more abundant minor species. Sculpins were most often collected in trawls. Unusually large numbers of sculpins

were trawled in April 1974 at both Cook and Warren Dunes, a phenomenon possibly related to sculpin spawning. Though present all year, sculpins were least abundant during the hottest months, when they probably returned to deeper, cooler waters. Larger catches at night probably reflect both daytime net avoidance and nighttime feeding activity. Sculpins were the second most abundant fish in 1974 impingement collections, possibly because of an attraction to the riprap area.

White suckers were gillnetted in the Cook Plant area all year, and were somewhat more abundant at Warren Dunes. Low catches during the March-April spawning season suggested they probably spawned elsewhere. White suckers evidently moved inshore at night as catches were larger at night, particularly at 6-m stations. Most suckers caught were adults; a few smaller fish were seined. White suckers were apparently susceptible to sea lampreys and to cancerous growths on the lips.

The biology of longnose suckers in the area was very similar to that of white suckers. Like white suckers, longnose suckers were present all year in Cook Plant study areas, slightly more abundant at Warren Dunes than at Cook, and showed a similar inshore movement at night. Juveniles of this species were also scarce, and spawning probably occurred outside the study area. In contrast to white suckers, large gill net catches of longnose suckers at 21 m suggested this species may range into deeper water.

One species which increased in 1974 catches compared to 1973 collections was gizzard shad, which may have been attracted to Cladophora growth on the riprap. Juveniles were seined and adults gillnetted, both mainly during spring and autumn.

Carp were most abundant May-August, with catches directly correlated with water temperature. In 1973, Cook Plant catches were larger than Warren Dunes catches, but in 1974, both areas yielded about equal numbers of fish. Adult carp dominated collections. They were collected primarily in night gill nets and secondarily in night seines.

Besides the abundant spottail, several other species of minnow were seined, most often at beach station B (S Cook) where gravel and rubble bottom provided a somewhat unique habitat. Among the most common were longnose dace, which were most abundant in night seines in autumn of both 1973 and 1974. Pelagic emerald shiners also were common in day seine catches, especially during late summer and autumn. They were more abundant in 1973 than in 1974. Only a few specimens of the following species were collected: sand shiners, seined in 1974 (possibly misidentified in 1973); golden shiners, seined in both 1973 and 1974; bluntnose minnow, seined in 1974; fathead minnow, seined in 1973 and impinged in 1974.

Centrarchids (mostly immature) were uncommon in our field samples. More were collected in 1974 than in 1973; most were seined or impinged, which led us to believe they were attracted to the riprap and Cladophora growth around the intake structures. Among the sunfish, only bluegills were

collected regularly. Most of these were immatures seined in spring 1974 at Warren Dunes. Of the other species, green sunfish were seined and impinged in 1974, largemouth bass were seined in 1973 and 1974, rock bass were seined in 1973 and seined, gillnetted and impinged in 1974, pumpkinseeds were impinged in 1973 and 1974, and one smallmouth bass was gillnetted in 1974.

During 1974, 125 lake trout were caught in standard series nets and 84 in supplementary netting; similar numbers were taken during 1973. Peak catches corresponded with seasonal onshore and alongshore spawning movements and 80-90% of the fish were caught at night. Fifty-nine percent of all fish were taken at temperatures between 8.0 and 11.9 C. Eighty-eight percent of fish were captured within a 160-km radius of planting location. Bulk of 1973-1974 caught fish were adults 600-800 mm ranging from 112 to 817 mm. Age ranged from 1 to 8 yr with 5- and 6-yr-old fish comprising more than half of the catch each year, indicating rapid attrition of older fish from the population. Gonad maturation peaked during October-November each year. Natural recruitment was not observed, but windrowed eggs were seen on the beach on one occasion following a storm. Approximately 88% of fish captured during fall had empty stomachs revealing cessation of feeding during spawning period. Lamprey scars were noted on 22% of all fish but less than 1% of fish bore fresh wounds; number of wounds increased rapidly with age.

Standard seines fishing caught 51 brown trout during 1974, primarily in May and June; 76 were captured during 1973. Size ranged from 102 to 693 mm with a preponderance of 100-200 and 400-500-mm fish. The data did not suggest many consistent activity patterns but revealed general presence of large fish inshore during March-May followed by offshore movement during summer; juvenile fish were present inshore throughout most of both years. Large fish were most frequently taken at temperatures between 4 and 14 C; smaller fish preferred higher temperatures. Gonad data suggested an autumnal spawning period.

Only eight rainbow trout were caught during 1973 while 86 fish were netted in standard series fishing during 1974, including 72 immature fish taken in seines. Fraction of natural to total recruitment was unknown, but yearly variation in numbers of juveniles seined may reflect differences in fish plantings. Analysis of distributional and gonad data revealed inshore presence and an extended spawning period (October-March) for adult fish and possible overlap among fall and spring spawners. Juvenile fish were present inshore primarily during spring and summer. Adult fish were captured at temperatures between 3 and 11 C, juveniles between 17 and 25 C and yearlings from 8 to 13 C.

Forty-one chinook salmon were caught in 1974 standard series nets, most during September; 26 were taken in 1973. Size ranged from 79-998 mm but small fish 80-225 mm predominated the 2-yr catch total. Adult fish were gillnetted primarily at night during fall, corresponding with nocturnal inshore spawning movements. Juvenile fish were most abundant inshore during late spring and early summer. Large fish were taken most frequently at temperatures between 7 and 17 C while small fish were caught over a wider

(9-22 C) temperature spectrum. Maturation of gonads peaked during. August-October.

We caught 153 coho in standard series fishing during 1974 in contrast to 32 caught during 1973. Most coho in 1974 were captured in May; some were also caught in August and November. Data for both years indicate predominately nocturnal activity for this species. Fish 70-90 mm, 100-170 mm and longer than 170 mm were caught at temperatures approximating 11 C, 11-17 C and less than 11 C, respectively. Length-frequency distribution was bimodal at 100-200 mm and 450-550 mm. Seine data suggest yearling coho inhabited the beach zone from April (subsequent to planting) until early summer when they followed the offshore retreat of the thermocline; similar seasonal migrations were observed for adults. Gonad data documented fall spawning; extent and variation of natural recruitment remains unresolved.

During 1974, 225 unidentified coregonids (primarily _C. hoyi_) were captured (82% in a July upwelling when water temperature was 11-15 C), compared to 148 caught during 1973. Most were small fish taken in deeper water trawls, closer to the main offshore population. In contrast to 1973 catches, most 1974 fish were immature (76.5%) and less than 200 mm (88%); 15.2% of remaining fish were females, 8.3% were males. Age of 1974 adults ranged from 3 to 7 yr. Water temperature and upwellings appeared to strongly influence bathymetric movements of chubs. Seasonal maturation of gonads and appearance of YOY fish suggest principal spawning during February-March.

During 1973, two small lake whitefish were collected in standard series trawls and a larger fish was gillnetted in supplementary netting. In 1974, a single fish was taken in standard series netting and four fish were taken in supplementary gill nets. Scale readings of 1974 fish showed age ranged from 3 to 7+ yr.

A single large female lake herring was gillnetted in a supplementary net during February 1973 and another during December 1974. Spent condition of both fish coincided with the early winter spawning period documented for the species.

Several other species were caught regularly in low numbers. Among these were ninespine stickleback adults, which were trawled and seined mostly during May in 1973 and 1974. They were collected most often at night and more were caught at 9-m than at 6-m stations. Channel catfish were caught in gill nets, seines and trawls and included both immatures and adults. A number of catfish were also impinged in 1974. Northern pike were mostly 2-3-yr olds collected most often in gill nets and occasionally in seines. Only half as many pike were collected in 1974 as were caught in 1973. More than twice as many burbot were collected in 1974 than in 1973, mostly in night gill nets during winter and spring. A few larval burbot have also been collected indicating that the Cook Plant area may be used for spawning.

Some species were rarely collected. Black bullheads were seined and impinged during 1973 and 1974. Mudminnows were collected only from impingement samples in 1973 and 1974. Quillbacks were seined both years and one small specimen was impinged in 1974. Lake sturgeon (a threatened species) were gillnetted in both 1973 and 1974.

Alewife larvae were the most abundant larval fish collected during 1973-1974. They were common from June through August from the beach zone out to 21 m, with spawning occurring from late May through all of August in most years. Alewives were collected more often during the night than during the day which was attributed to daytime net avoidance. In the beach zone, larger, and usually more larvae, were collected during the day. We attributed this pattern to movement of larger alewife larvae offshore at night and onshore during the day.

No discernible pattern in vertical distribution of alewives was observed; they appeared to be common at all depths, and thus very susceptible to entrainment, particularly at small sizes. Alewives were generally found in epilimnion water, being more concentrated in 1973 compared to 1974, which was the result of 1973 being a warmer year in general.

Spottail shiner larvae were first recorded on 13 May in 1974, which was almost a month earlier than the main occurrence of spottails, which attained peak abundance during June and July. Spottails are believed to spawn inshore in 3-m or less water, although divers have documented some spawning on the intake structures at 9 m. Most larvae were collected in sled tows (up to 29,000/1000 m^3, the highest recorded larval concentration) in 3-m or less water at night, showing their demersal, inshore distribution. Their ability to avoid nets at a relatively small size is attributed to their robust body size. A few larvae were taken at 6- and 9-m stations. Larval spottails also grew faster during 1973 than in 1974. Potential entrainment impact on this species is expected to be low, based on their almost exclusive presence inshore of the intakes.

Rainbow smelt larvae were first found at beach stations (where spawning took place) around the end of April in 1973 and in early May in 1974. They were then found at 6- and 9-m stations sometime thereafter. A diel vertical migration of smelt larvae was observed where smelt were on or near bottom during the day and in upper waters at night. More were entrained at night as a result. Smelt larvae remained at 6- and 9-m contours throughout summer. Unlike alewife, which showed a wide range of lengths at any particular time during their peak periods of abundance (due to constant recruitment), rainbow smelt larvae were almost unimodal in their length distribution.

Very few smelt were collected after their peak abundance in April-May. They were next collected via trawl in August. Larval smelt concentrations have declined consistently over the years of the study from peak densities in 1973 to very low levels in 1977.

Yellow perch spawn somewhere outside the immediate Cook Plant vicinity, then larvae appear sometime between late May and mid-June, apparently drifting from their spawning sites according to local winds and currents. Larvae were generally most common at 6- and 9-m stations, were mostly caught at night (due to net avoidance) and inhabited the upper reaches of the water column. Yellow perch greater than 8 mm were never collected, showing their outstanding net avoidance capabilities. Larvae are known to be pelagic and to reside in the water column until they are about 30 mm when they become demersal. Larval perch are expected to have low entrainment potential because of their upper water column distribution.

Despite the fact that trout-perch were the fifth most abundant adult fish collected, only five larvae were collected during 1973-1974. Two larvae were collected in sled tows (demersal behavior), two were entrained and one was collected in the beach zone. Carp larvae, an apparent result of attraction of spawning adults to the thermal plume, were found only during operational years; none were found during 1973-1974. Burbot spawned in the area of the Cook plant, and their larvae were collected during 1975-1978; again none were observed during 1973-1974. Johnny darter and sculpin eggs were collected and hatched from riprap areas by divers and a few larvae were caught during regular field sampling.

Fish eggs, believed to be burbot, were recorded in January 1974 beach tow samples. Smelt eggs were next recorded, predominately in beach samples during the April-May spawning season of smelt. During June-September, peak concentrations of fish eggs were found in field and sled tow samples. Most (up to 18 million/1000 m^3) were collected on the bottom at beach stations. These eggs are believed to be mostly alewife eggs, but a large proportion of those inshore may also be spottail shiner eggs. At 6- and 9-m stations, densities of eggs were less than those found inshore during this summer period, with larger concentrations found in upper water strata at night, known spawning times of alewives. To date (1979) we have collected the eggs of alewives, spottail shiners, yellow perch, lake trout, sculpins and johnny darters in the vicinity of the Cook Plant. Carp eggs have undoubtedly been collected, but we have not been able to confirm this yet.

Entrainment sampling was sporadic in 1974 (93 total samples from May, July, August and November) due to ongoing plant construction and irregular running of the plant's circulating water pumps. However, larval fish entrainment did reflect abundance of adult fish which spawned in or near the study area. During 1974 four species of larval fish were collected from the plant's forebays. In May 1974 an estimated 46,000-177,000 smelt larvae/24 h were entrained during 2 days of sampling at the power plant. During July 1974 alewife larvae were entrained; while in August, alewife, spottail shiner and trout-perch larvae were entrained. Yellow perch, sculpin and trout-perch larvae were not as susceptible to entrainment as alewife. A comparison of the lengths of larvae caught in the field with those collected by our diaphragm pumps sampling entrained water showed generally that a decreasing proportion of the larvae population was sampled the larger the

larvae grew. We recommend for power plants similar to the Cook Plant, that if possible, entrainment sampling be conducted with plankton nets directly in the discharge forebay (if no mortality studies are needed), filter as much water day and night as possible especially during spawning periods, and conduct a comprehensive field sampling program concurrent with entrainment sampling.

Impingement collections from Cook Plant traveling screens during 1974 yielded 14,848 fish (432 kg) for 207.3 x 10^9 liters of circulating water pumped. While operational impingement rates cannot be predicted from preoperational rates, number of fish impinged as well as species composition appeared to be more closely related to local abundance than to volume or rate of water pumped.

Twenty-three species of fish were impinged. Alewife was most abundant (85% of total number impinged) followed by slimy sculpin, yellow perch, rainbow smelt, trout-perch, spottail shiner and johnny darter. Largest numbers of alewives, slimy sculpins, smelt, spottail shiners and trout-perch were collected during spring and summer when they were also most abundant in field catches. Yellow perch, however, were most often impinged in December. Alewives, spottail shiners and slimy sculpins were also impinged more often in December than was expected from field catches.

Species composition of impingement catches usually paralleled species composition of field catches. Slimy sculpins, however, were much more numerous in impingement than in field caches, possible due to development of a local population on the riprap around the intake structure. The size range of impinged fish also was similar to size range of field-caught fish, though fish under 50 mm were rarely impinged.

When length-weight regressions of impinged and field-caught fish were compared, impinged alewives were found to have an adjusted mean weight less than field-caught alewives. Whether alewives were weakened or less robust when they entered the forebay, or became so during a long residence time in the forebay is unclear. Results of comparing length-weight regressions for other species were inconclusive.

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